# Processing of High Resistivity Silicon

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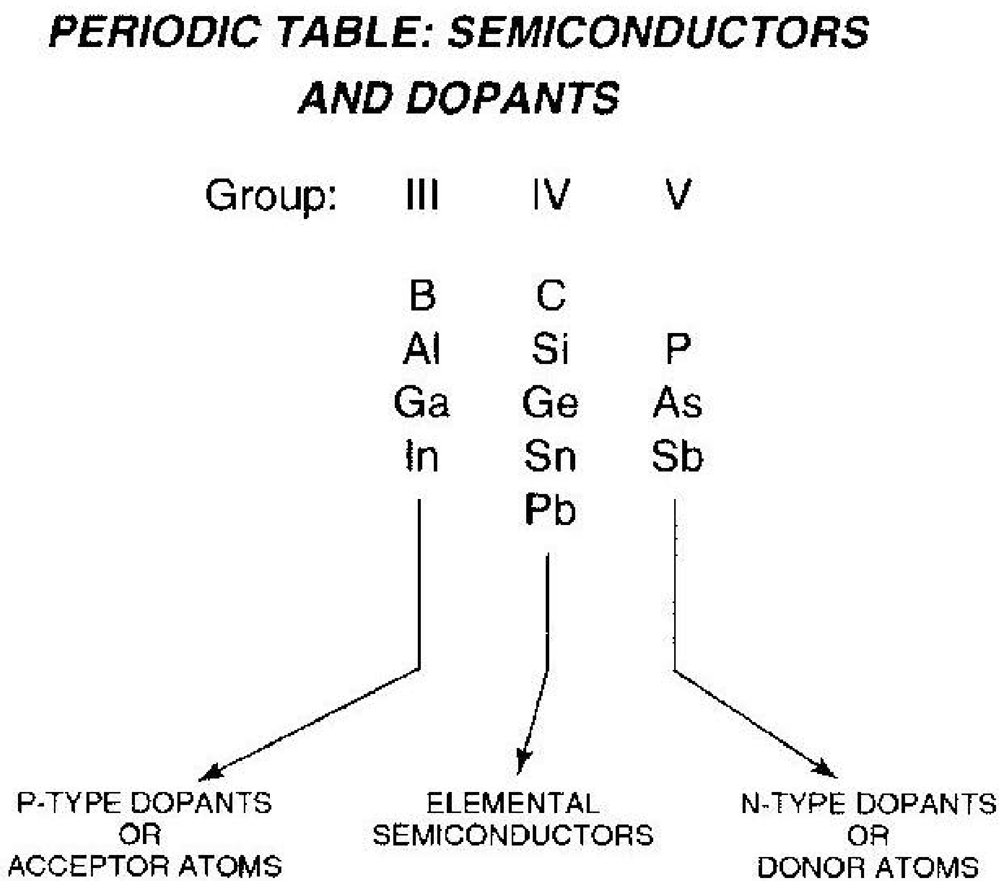
# Content

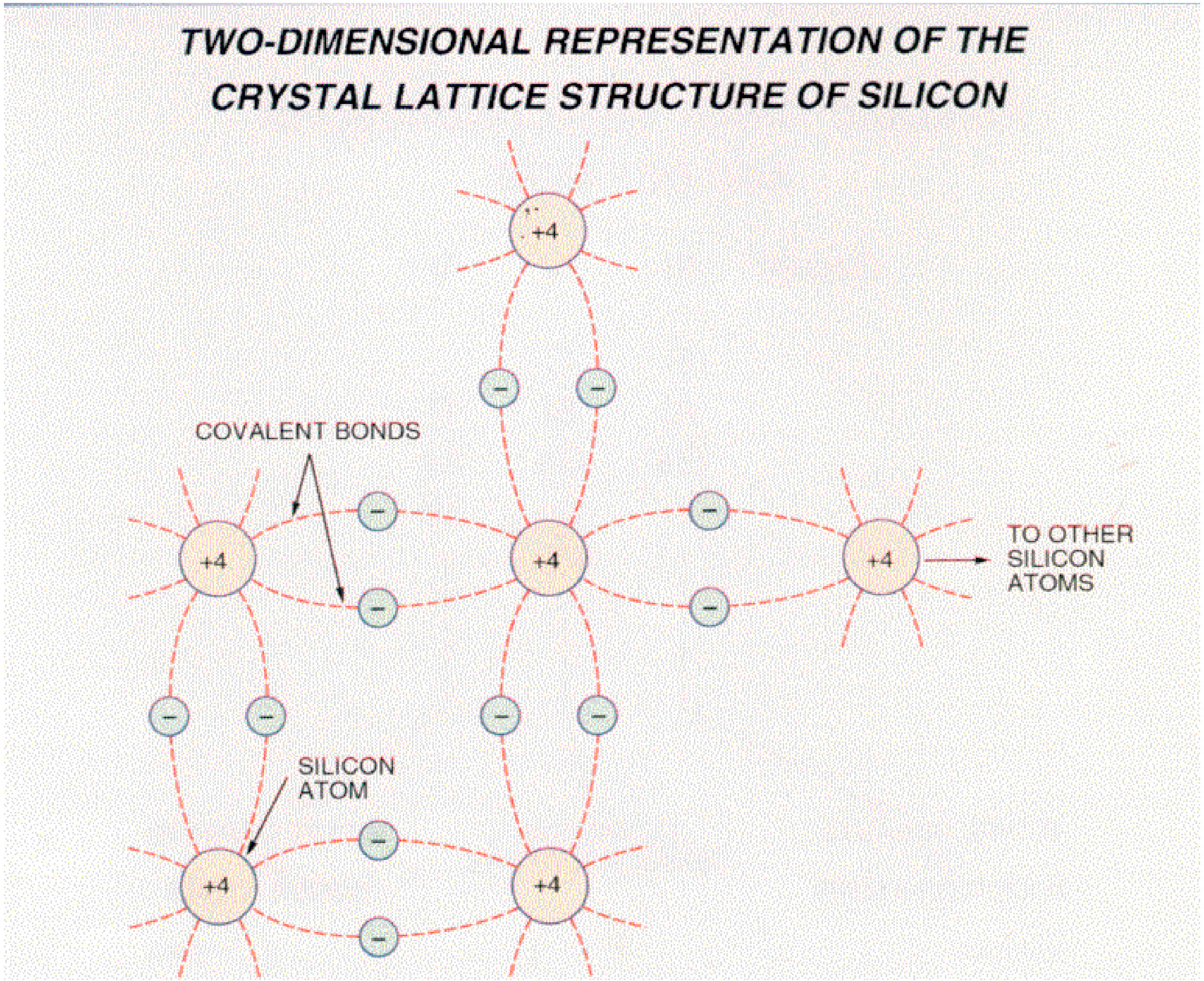
- Basic silicon properties
- Wafer preparation
- Oxidation process
- Photolithography process
- Etching process
- Ion implantation
- Metalization process

# Basic Silicon Properties

## Silicon Material

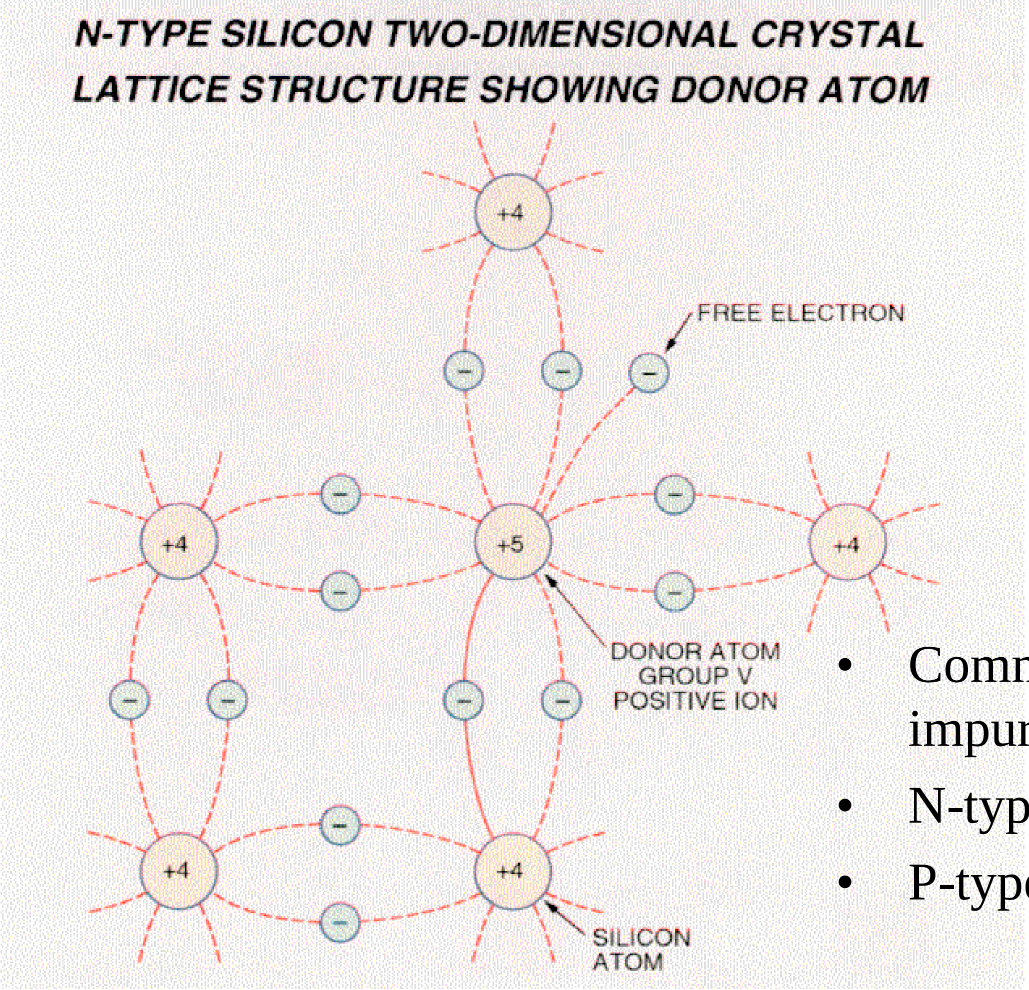


# Basic Silicon Properties
## Silicon Lattice



# Basic Silicon Properties

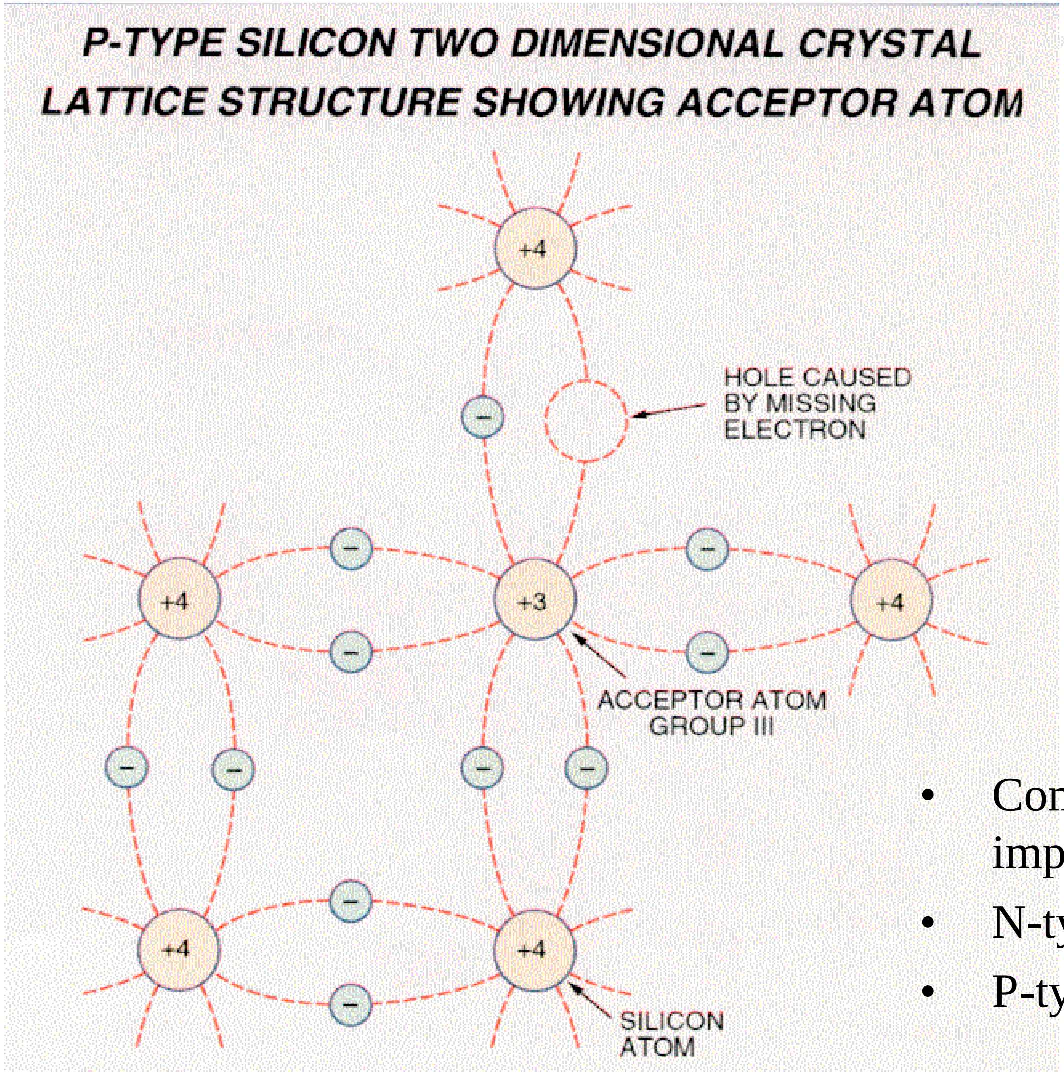
## N-Type Silicon




- Common Doping impurity: B, P, As
- N-type: $e^-$, free carriers
- P-type: $h^+$, free carriers

# Basic Silicon Properties

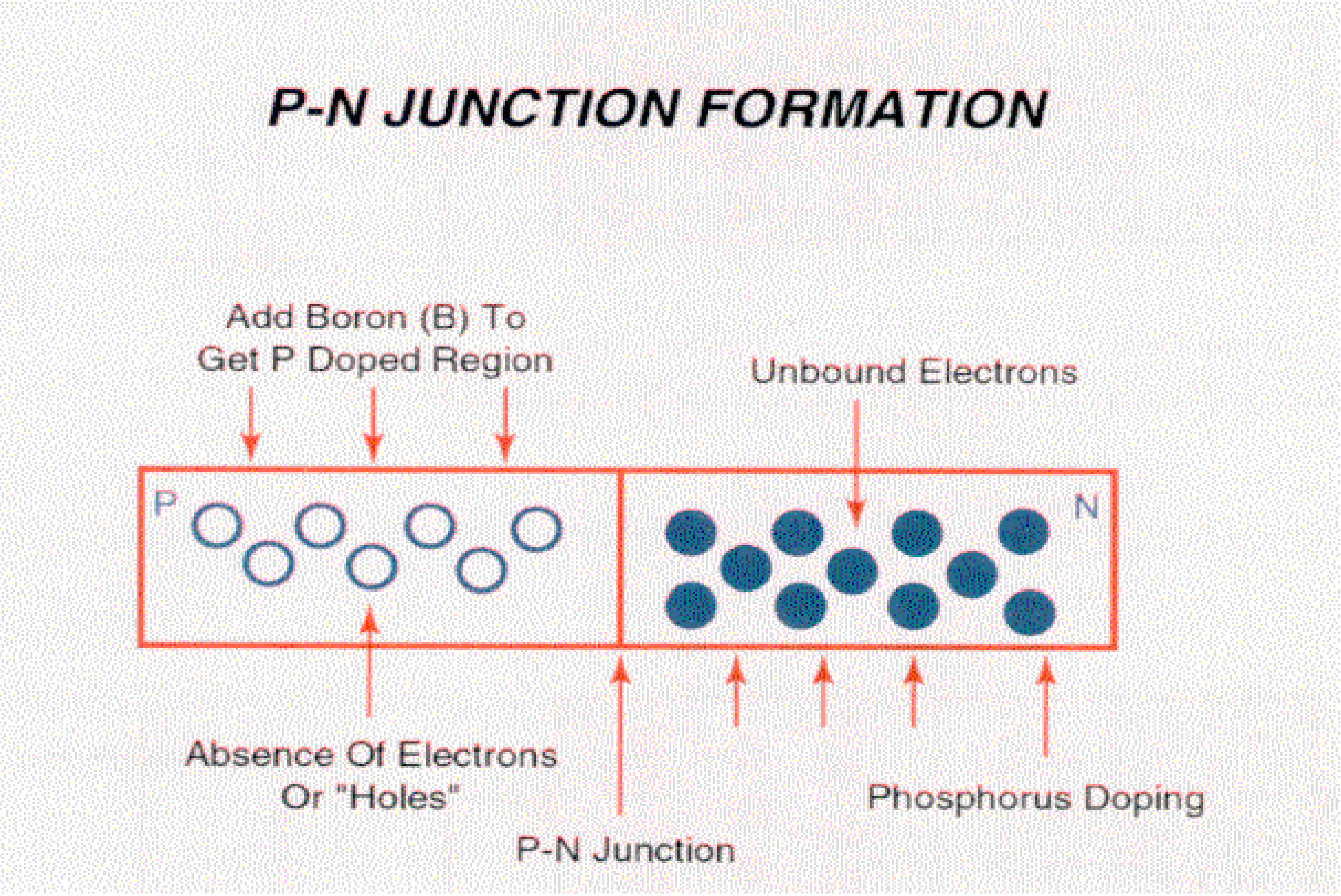
## P-Type Silicon




- Common Doping impurity: B, P, As
- N-type: $e^-$, free carriers
- P-type: $h^+$, free carriers

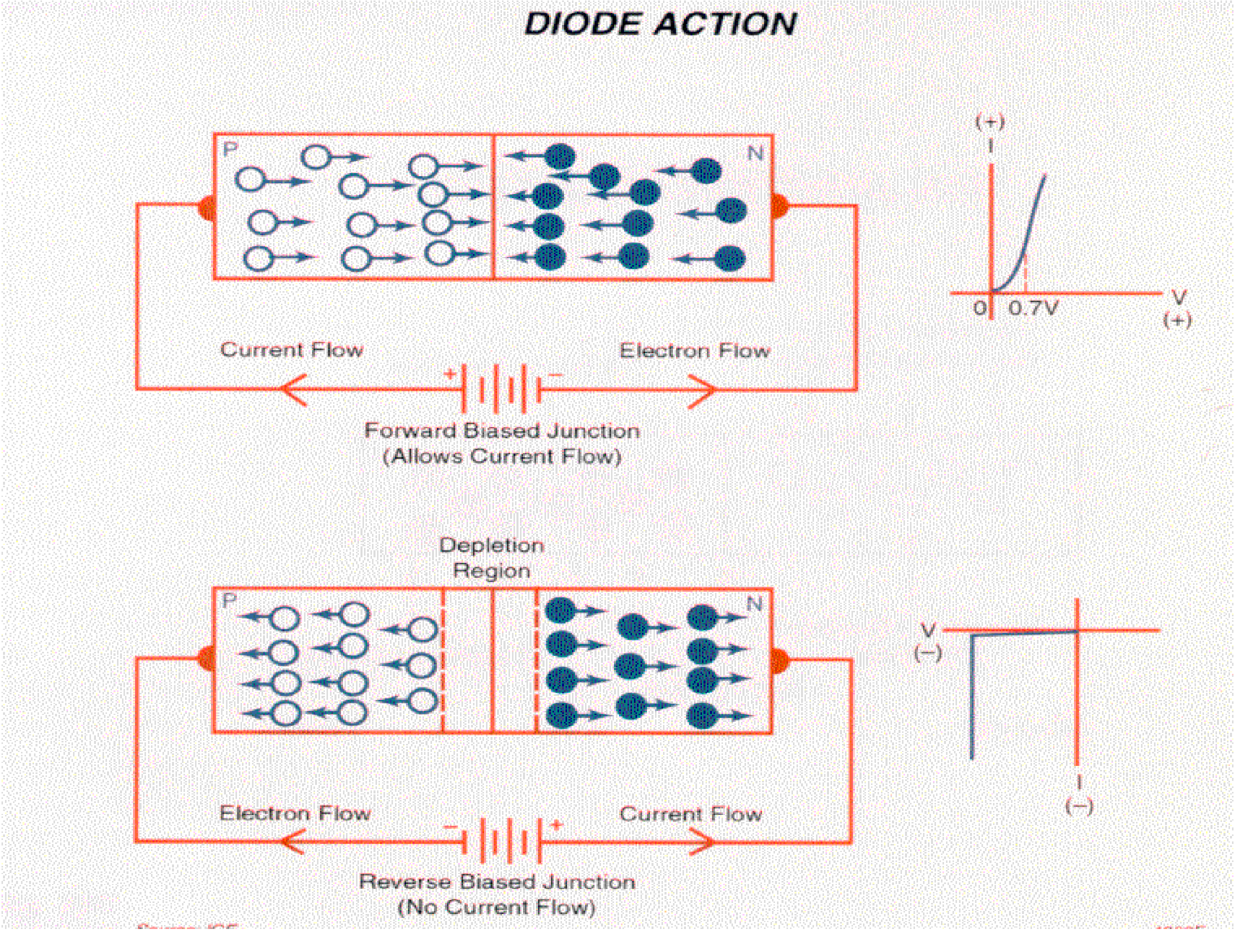
# Basic Silicon Properties

## Junction



# Basic Silicon Properties

## Rectify Diode



# Basic Silicon Properties
## Diode Detector

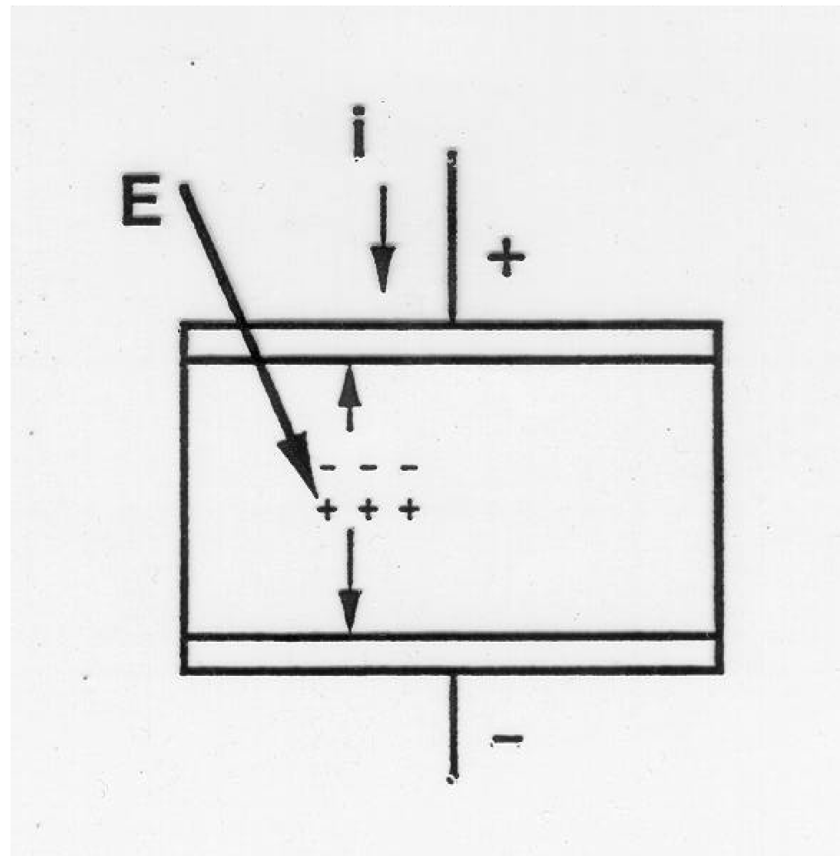
- P-type: 0.1μm
- N-type: 200-500μm
- $W=(2\varepsilon_s V/qNd)^{1/2}$

  $Nd=1/q\mu\rho$

  $\rho = W^2/(2\varepsilon_s \mu V)$

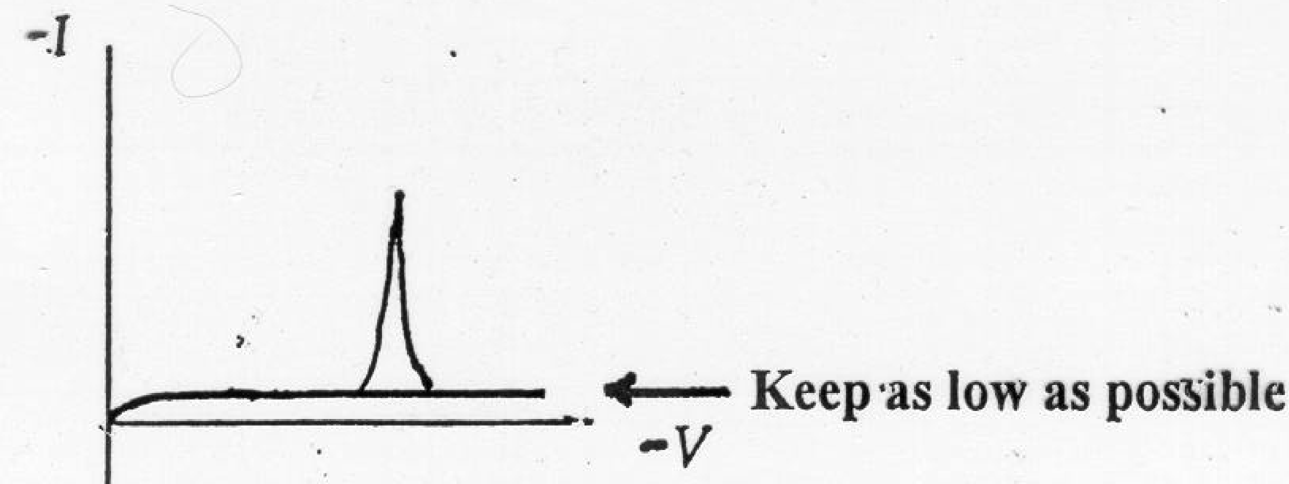
  V~100V, W~300μm,

  ρ ~3kΩcm



# Basic Silicon Properties

## I-V Characteristic of Detector




**Leakage Current**

$$\mathbf{I = I_{surf} + I_{bulk} + I_{diff}}$$

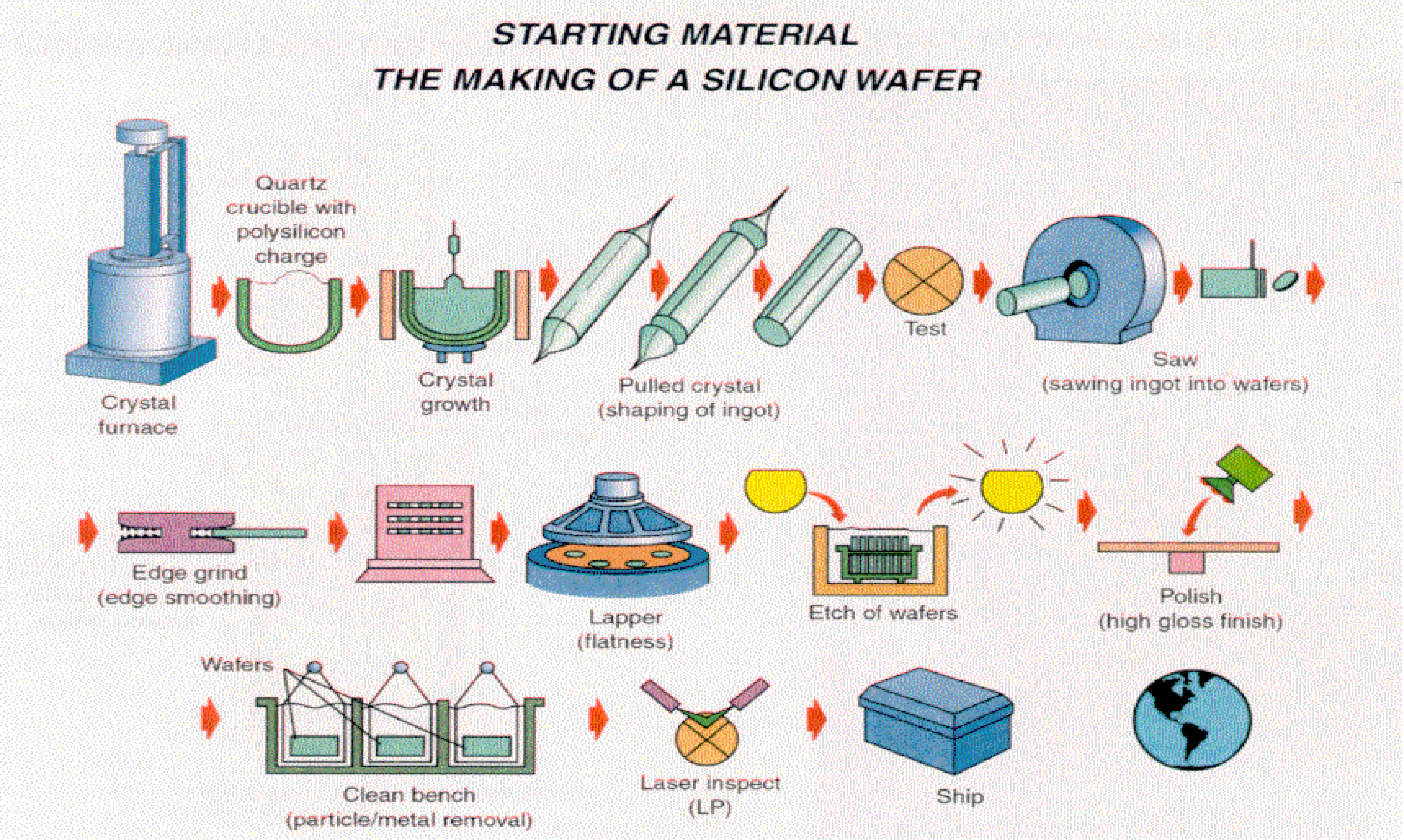
# Wafer Preparation

Device processing requires high quality wafers:

- Flat
- Smooth
- Uniform
- Clean

# Wafer Preparation

## From Ingot to Wafers



# Wafer Preparation
## Cleaning

- Mechanical cleaning
  - Spray rinsing
  - High pressure jets
  - High speed scrubbing
- Chemical cleaning
  - RCAI ($NH_4OH$:$H_2O_2$:$H_2O$)
  - RCAII (HCL:$H_2O_2$:$H_2O$)
- Mechanical-chemical cleaning
  - Megasonic +Chemicals

# Wafer Preparation
## Contaminants

- Heavy metal
  - Fe, Cu, Ni, Zn, Cr, Au, Hg, Ag (They create trapping sites and lower the performance.)
- Alkali metals
  - Na, K (They create positive ions)
- Light elements
  - Al, Mg, Ca, C, Cl, F (Less serious)

# Wafer Preparation
## Chemical Solutions

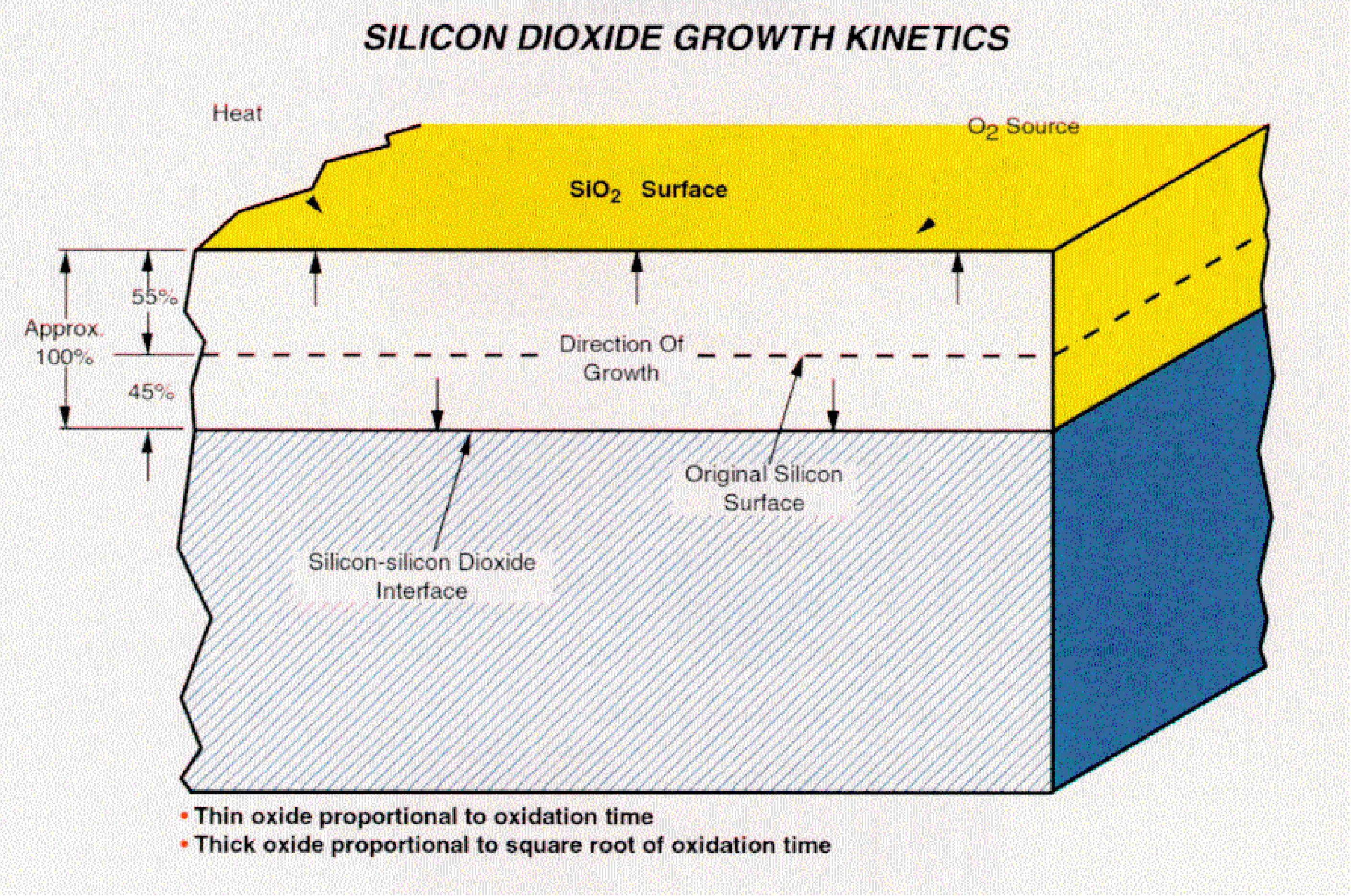
PARTIAL LIST OF SILICON WAFER CLEANING SOLUTIONS

| Solution | Chemical Symbols | Common Name | Purpose or Removal of: |
|---|---|---|---|
| Ammonium hydroxide/ hydrogen peroxide/ water | $NH_4OH/H_2O_2/H_2O$ | RCA-1, SC-1 (Standard Clean-1), APM (ammonia/peroxide mix), Huang A | Light organics, particles, and metals; protective oxide regrowth |
| Hydrochloric acid/ hydrogen peroxide/ water | $HCl/H_2O_2/H_2O$ | RCA-2, SC-2 (Standard Clean-2), HPM (hydrochloric/peroxide mix), Huang B | Heavy metals, alkalis, and metal hydroxides |
| Sulfuric acid/ hydrogen peroxide | $H_2SO_4/H_2O_2$ | Piranha, SPM (sulfuric/ peroxide mix), "Caros acid" | Heavy organics |
| Hydrofluoric acid/water | $HF/H_2O$ | HF, DHF (dilute HF) | Silicon oxide |
| Hydrofluoric acid/ ammonium fluoride/ water | $HF/NH_4F/H_2O$ | BOE (buffered oxide etch), BHF (buffered hydrofluoric acid) | Silicon oxide |
| Nitric acid | $HNO_3$ | — | Organics and heavy metals |
| Potassium Hydroxide | KOH | — | Silicon |
| Hydrofluoric and/ Nitric acid | $HF/HNO_3$ | — | Silicon; Glass |

# Oxidation Process

- Silicon Dioxide ($SiO_2$) provides
  - High quality insulating barrier
  - Impurity-diffusion barrier
  - Passivation
  - Gettering of impurities in Si

# Oxidation Process



# Oxidation Process

## Thickness

For long time growth

$$Xo = \sqrt{Bt}$$

B: parabolic rate constant

t: time

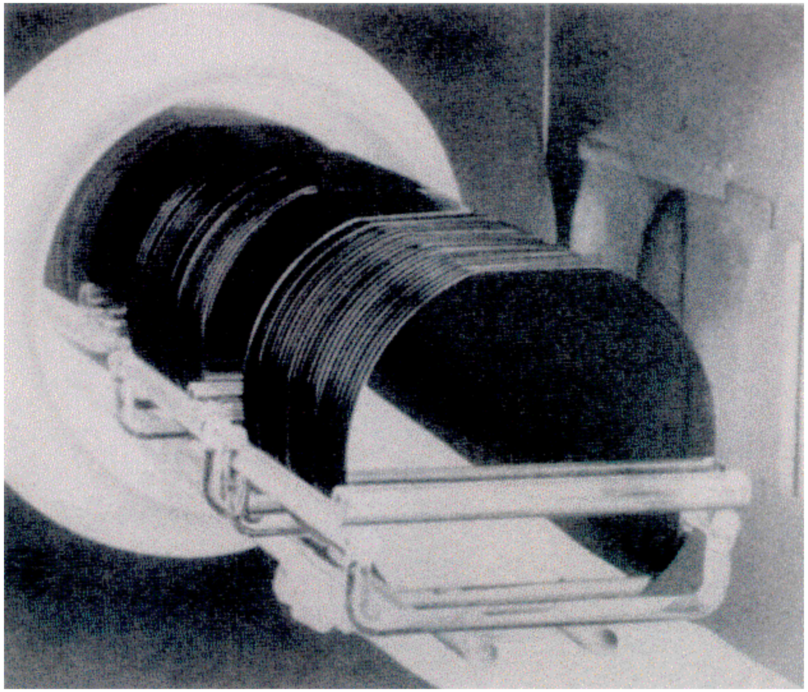
# Oxidation Process

## Important Influence

- Temperature control
- Crystal orientation
- Dopant concentration
- Ambient in the process chamber
- Concentration of Chlorine added to ambient
- Pressure of chamber
- Post oxidation anneal
- Prior operation

# Oxidation Process
## Parameters

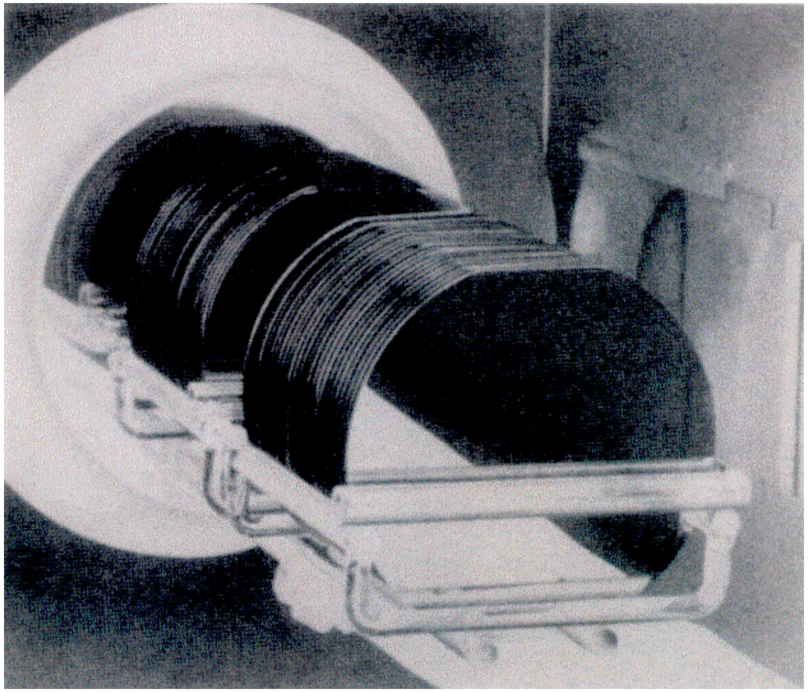
- Slower growth in dry oxygen results in a denser, higher quality oxide
- The addition of chlorine during oxidation improves oxide quality
- Oxide thickness can be estimated by the color or other techniques.



# Oxidation Process
## Our Parameters

- Dry oxygen grown oxide  (32hr)
- 0.5% TCA
- About 0.5um thick

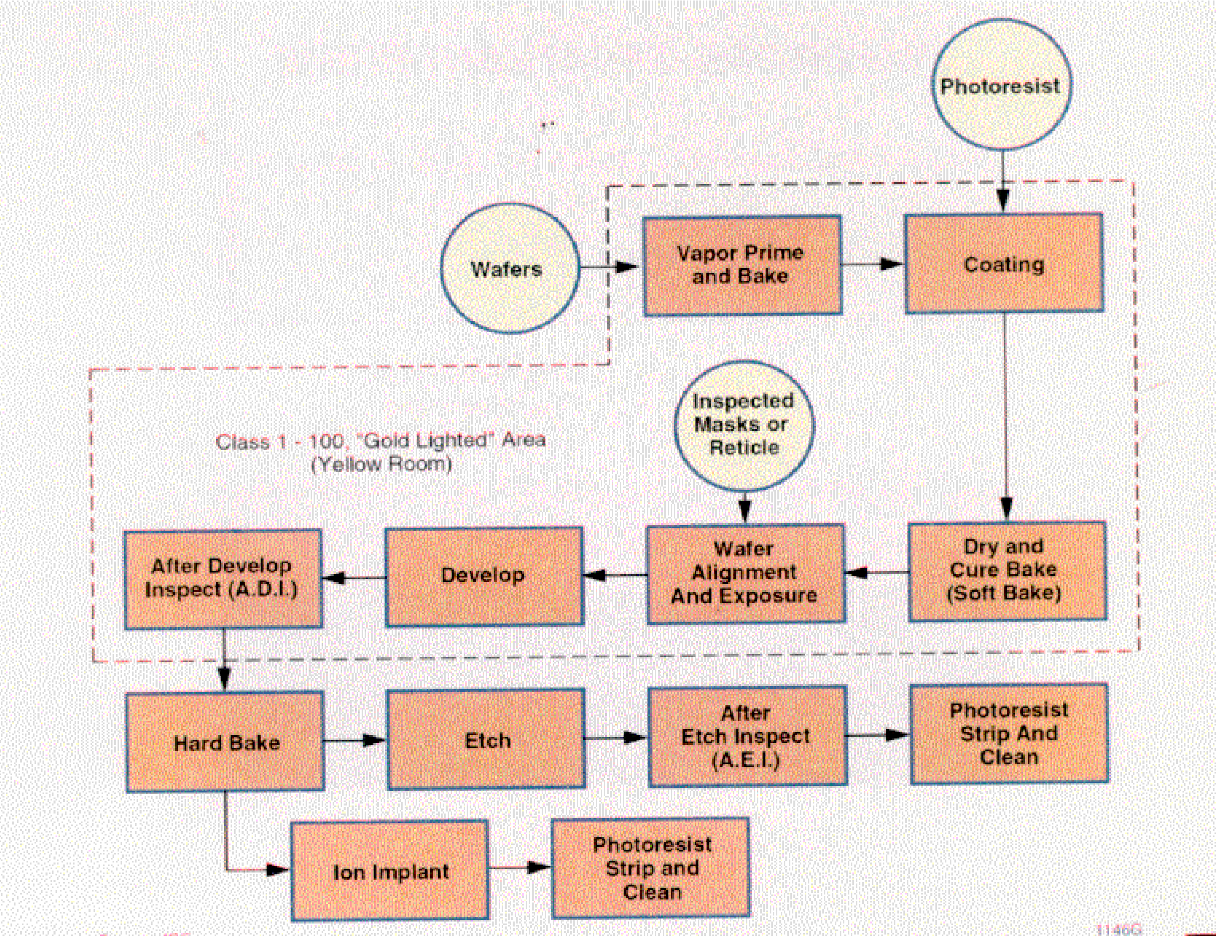
  (wafer about 200-500um)



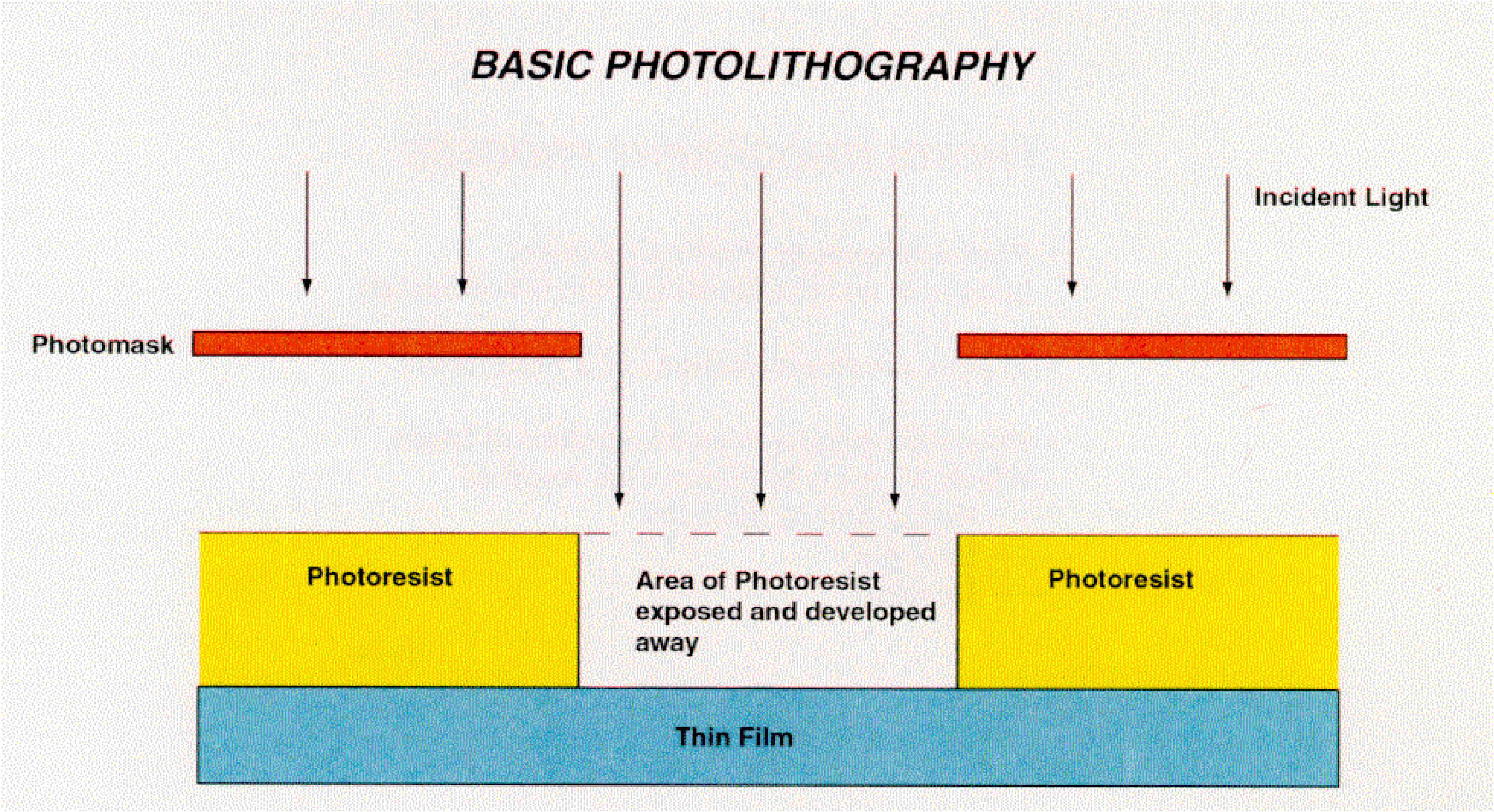
# Photolithography Process

- Produces optical images in a light sensitive film (Photoresist)
- Images are reproduction of photomask
- It is an integration of steps which strongly influence one another:
  - Photoresist and application
  - Exposure
  - Develop

# Photolithography Process
## Flowchart



# Photolithography Process

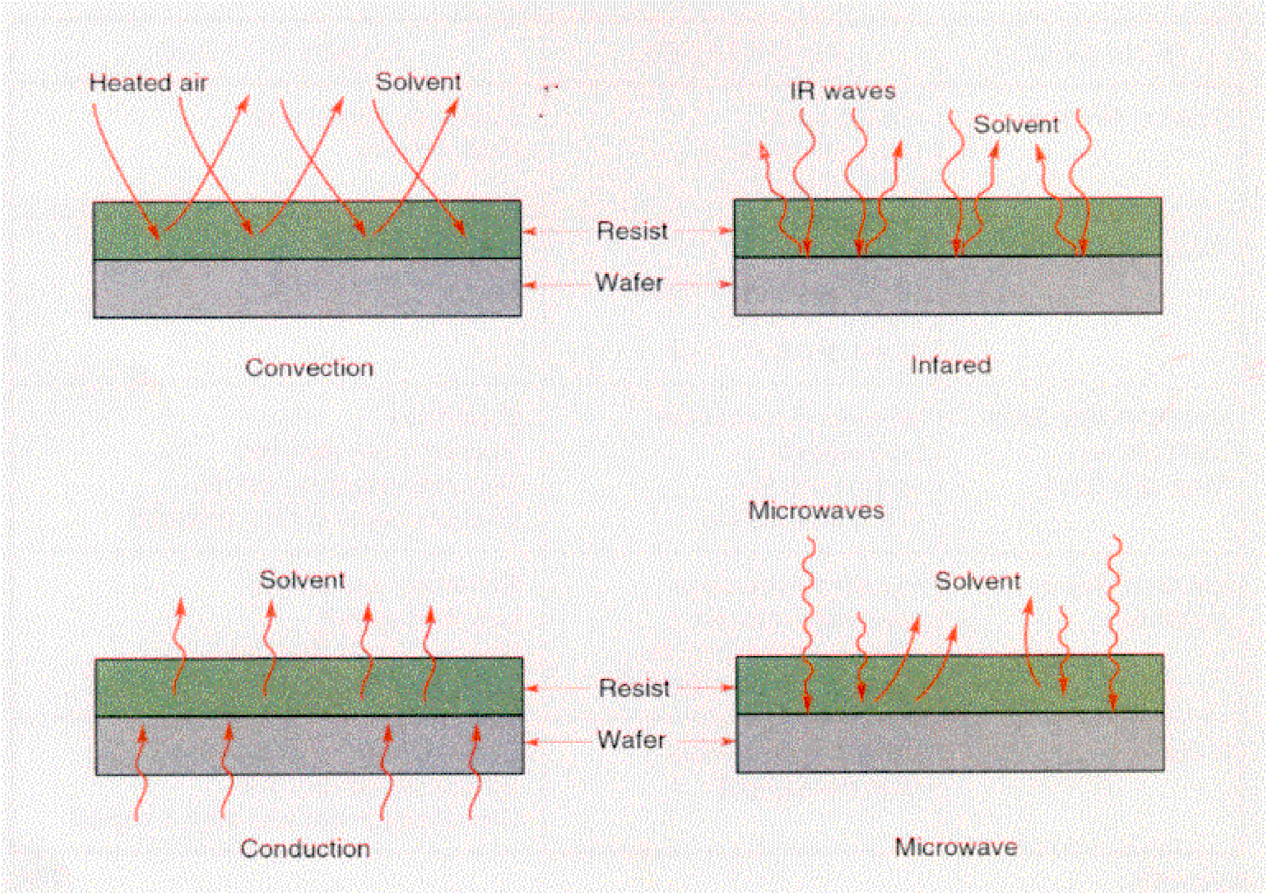


# Photolithography Process

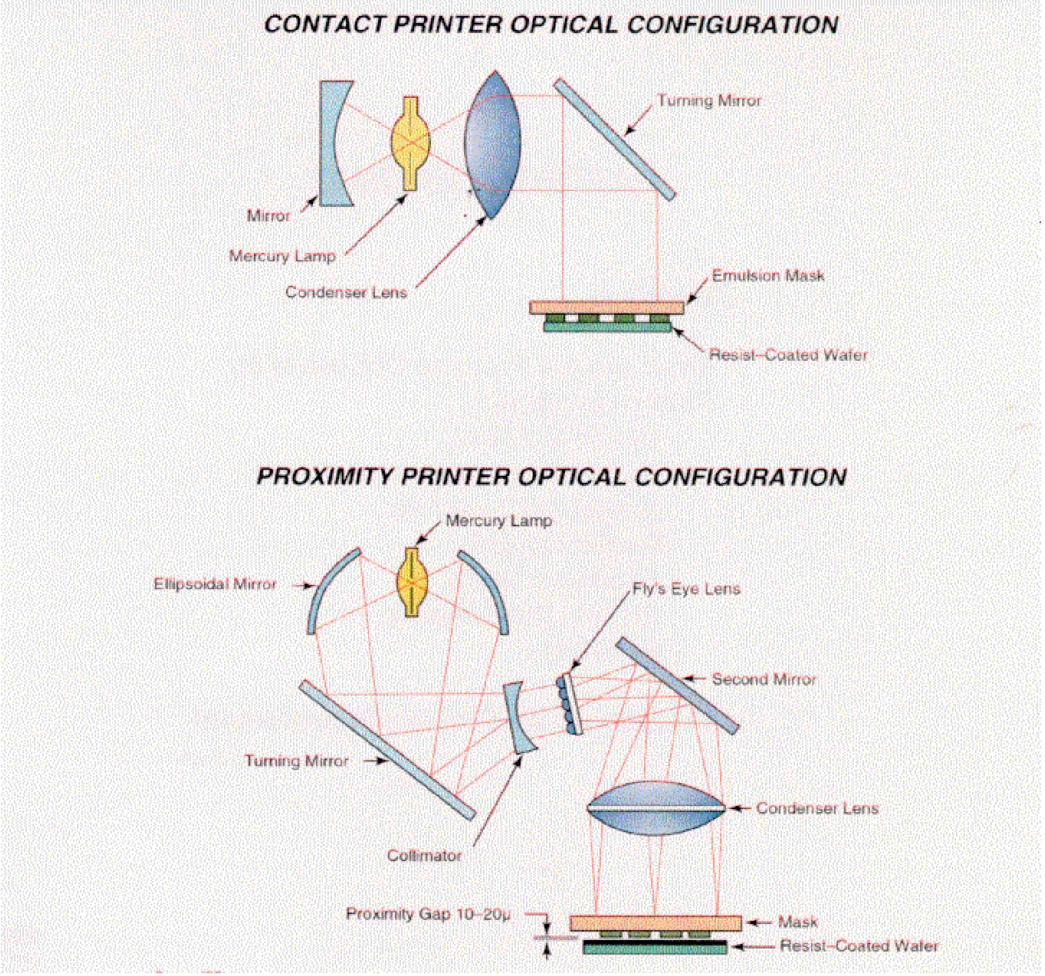
## Choice of Photoresist

| Characteristic | Positive Resist | Negative Resist |
|---|---|---|
| Exposure | Molecular changes permit dissolution of exposed regions. | Rely upon crosslinking for image formation. |
| Molecular Weight | No molecular weight changes — chemical change in non-image areas. | High molecular weight products formed during exposure. |
| Oxygen Sensitivity | No oxygen sensitivity. | Have oxygen sensitivity, causing exposure problems. |
| Removal | Easy removal, as no high molecular weight products present. | Are difficult to remove, due to high molecular weight. |
| Chemical Stability | Excellent chemical stability and good filtration flow rates. | Have marginal chemical stability causing low filtration flow rates. |
| Developing | Aqueous developing; the image is unaffected by the developer. Disposal is relatively simple. | Solvent developing; resulting in image swelling. Also, disposal is more difficult. |
| Coating Thickness and Resolution | Coating thickness can be equal to or greater than minimum image size. | Coating thickness must be 1/3 the minimum image size. |
| Step Coverage | Excellent, as thick coatings can be used. | Marginal, due to thin coating limitations. |
| Cost | Higher cost than negative resist. | Relatively inexpensive. |

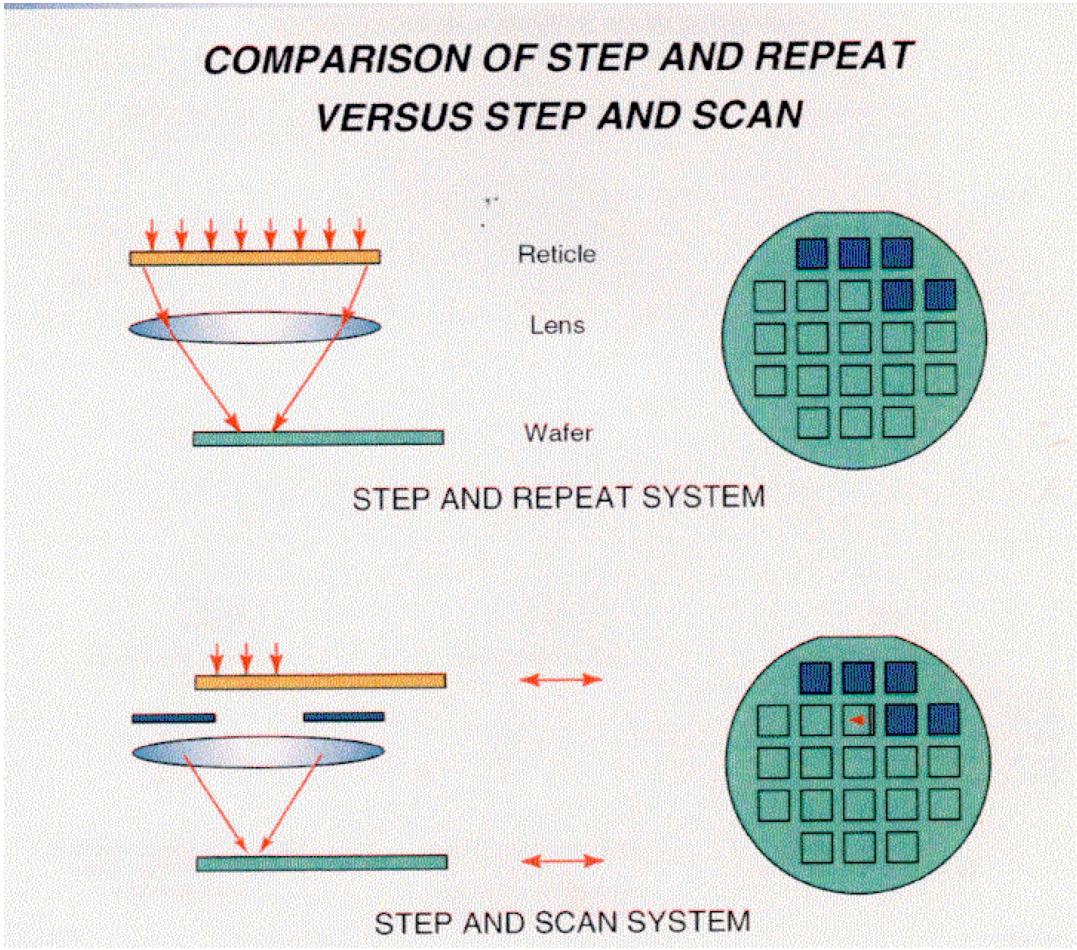
# Photolithography Process
## Method of Softbake



# Photolithography Process
## Exposure Technologies

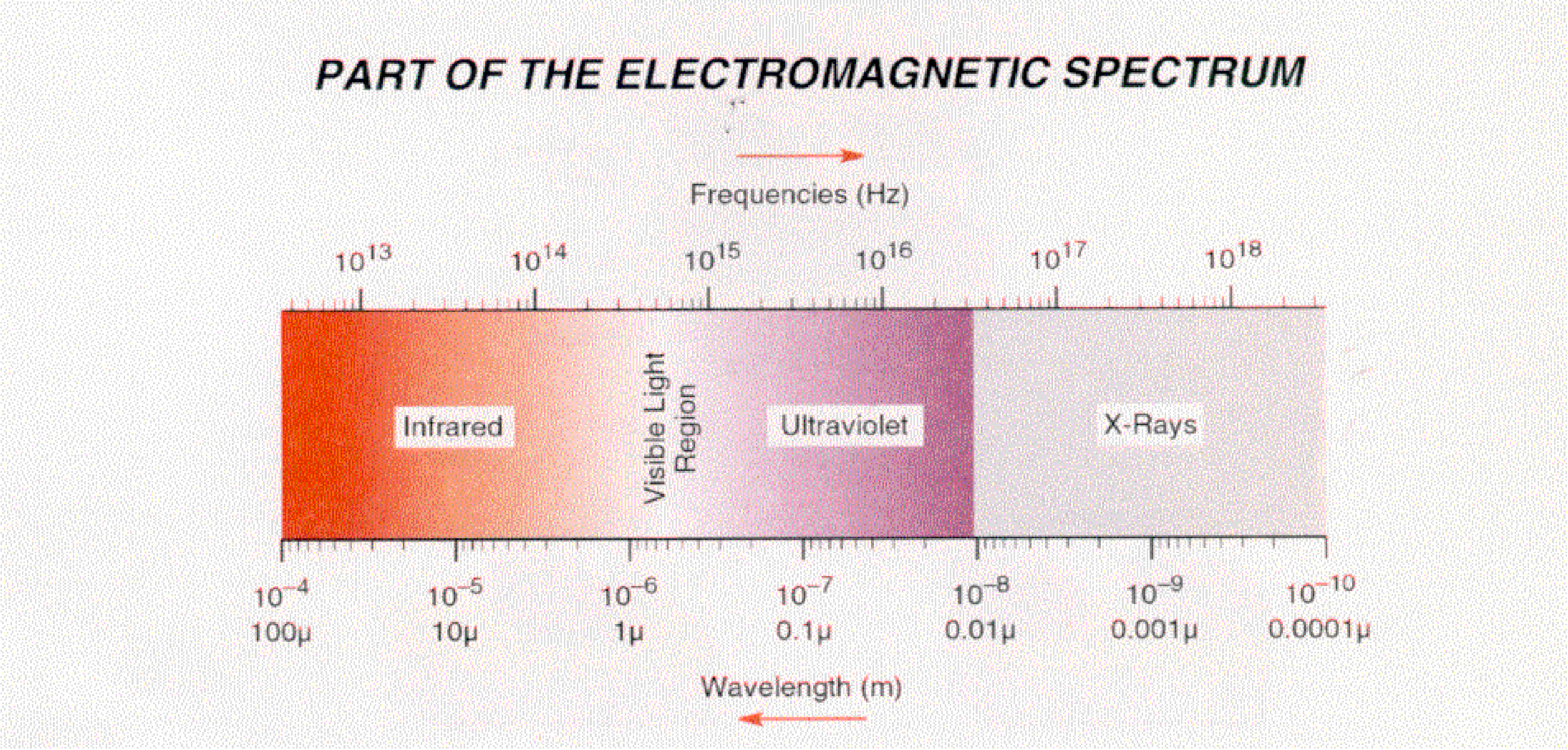


# Photolithography Process
## Industry Technology



# Photolithography Process

## Spectrum

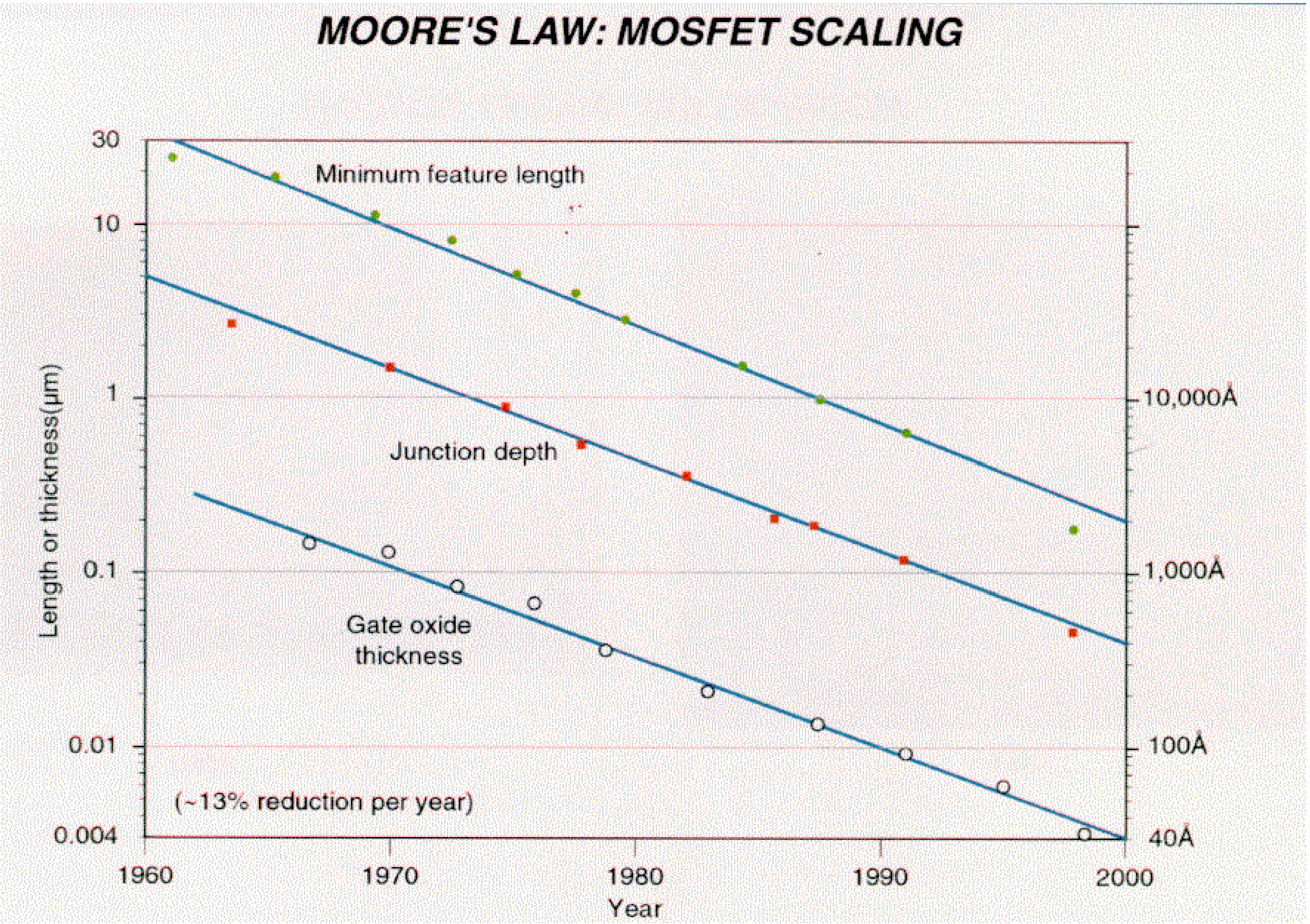


# Photolithography Process

## Advanced Technology

- Direct electron beam writing
  - Munch higher precision, higher resolution
  - Lower throughput
  - Complicated, expensive
- Projection e-beam
  - Higher throughput
- X-ray lithography
  - Difficult to precisely focus (very high theoretical resolution)
  - Masks must block x-rays yet maintain resolution
  - X-ray hazards

# Photolithography Process
## Industry Trend

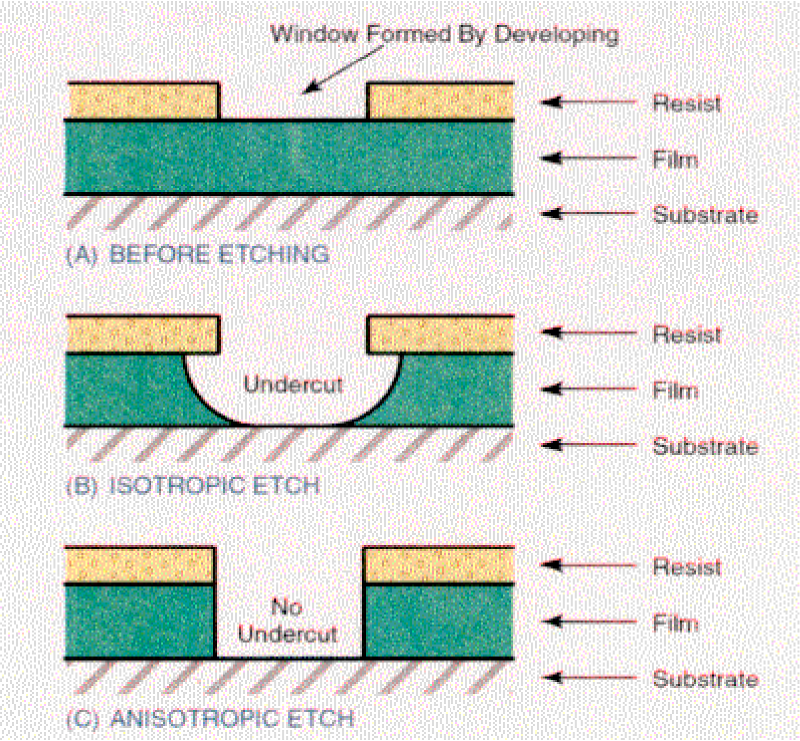


# Photolithography Process
## Our Data

- Photoresist: Positive, S1811 (Shipley)
  - 0.5μm~2.5μm
- Softbake: Hotplate contact or proximity
- Exposure: Proximity and Contact print, ultraviolet light
- Developer: MF-312 (Shipley)

# Etching Process
## Basic Etching techniques

- Wet etching
  - Chemical solution
  - Isotropic
- Dry etching
  - Chemical gas
  - Anisotropic



# Etching Process
## Wet Etching

- Advantages
  - Low cost
  - Reliable
  - High throughput
- Disadvantages
  - Isotropic
  - Resist adhesion
  - Non-uniformities

# Etching Process

## Chemicals

- Etching $SiO_2$: HF solution
- Etching Al: $HNO_3$+$H_3PO_4$+$C_2H_4O_2$ solution
- Etching Si: $HNO_3$+ HF solution
- Etching $Si_3N_4$:$H_3PO_4$ solution

# Etching Process
## Dry Etching

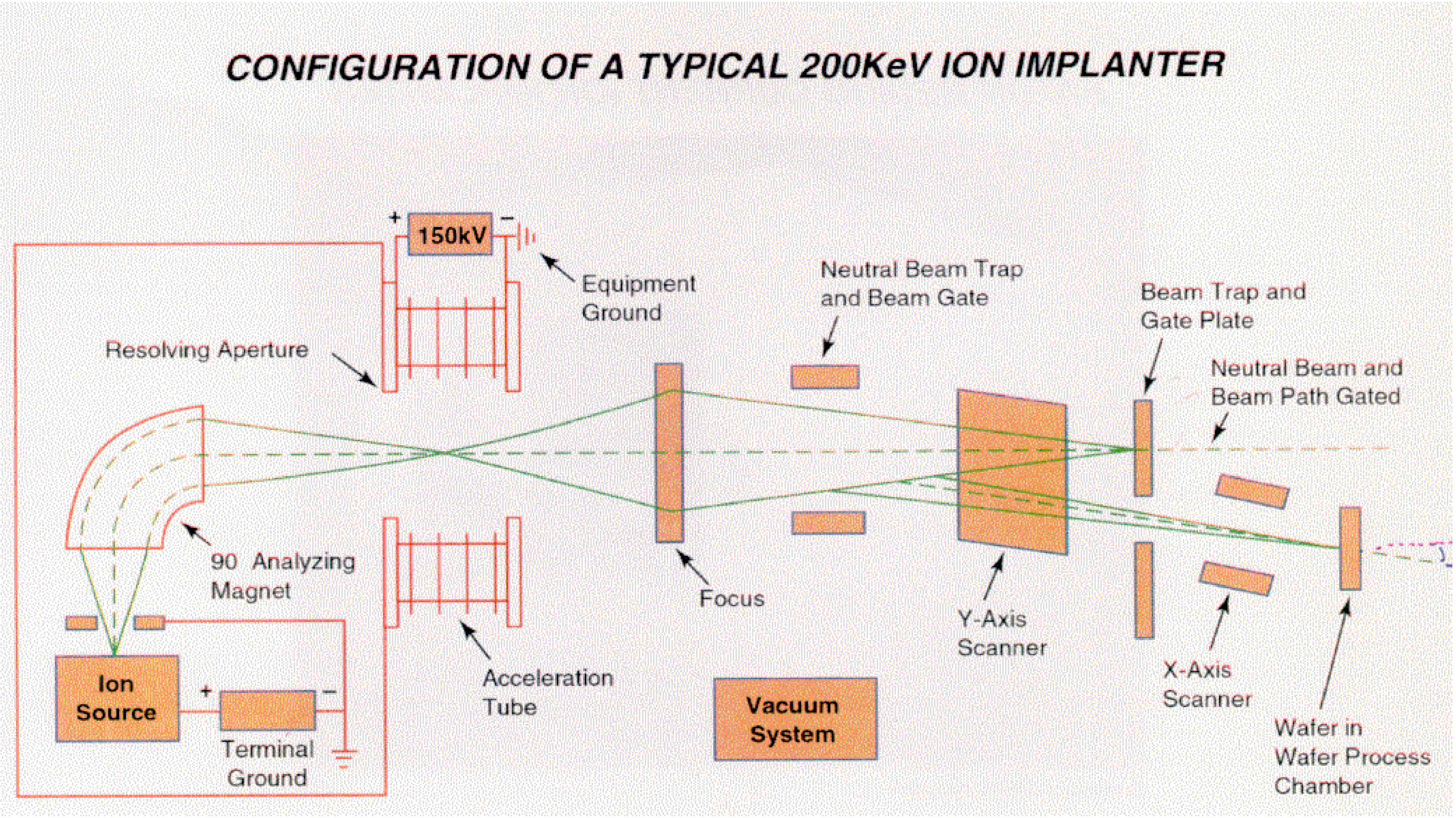
- Advantages
  - Anisotropic
  - Less chemicals
- Disadvantages
  - Complex equipment
  - Costly

# Ion Implantation Process

- Introduces dopants as ions at controlled energies
  - Profile is determined by ion energy
  - Dose is accurately measured from beam current and known scan areas
  - Ion species is selected by mass analyzer
  - Process is at room temperature permitting the use of photoresist for masking

# Ion Implantation Process

## Implanter



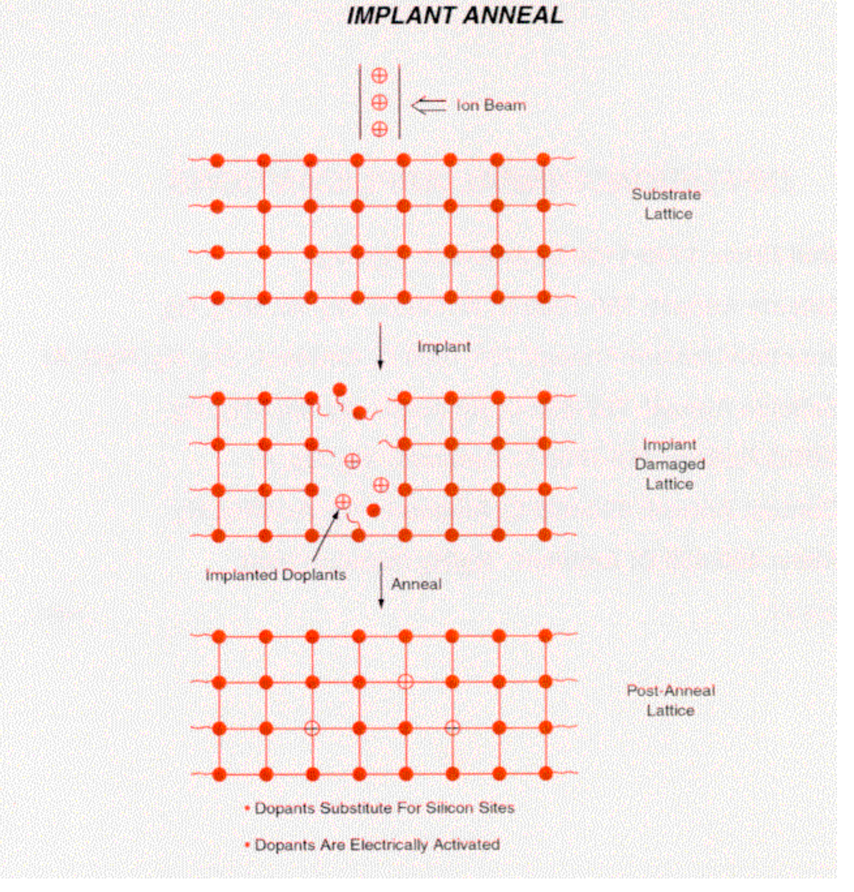
# Ion Implantation Process

- **Advantages**
  - Precise dose control
  - Extremely pure dopant beam
  - Small lateral distribution
  - Inject through a surface protective layer
  - Multiple implants
  - Highly abrupt junctions
  - Low temperature process
- **Disadvantages**
  - Surface damage
  - Expensive and complex equipment
  - Low throughput
  - Shallow implantation depth for heavy atoms

# Ion Implantation Process

## Post Implant Anneal

- High temperature process (600~1100 c)
- Repairs damage
- Electrically activates dopants
- Ambient: $O_2$, $N_2$, $N_2O$, Ar



# Metalization Process

- Provides contacts and interconnections
- Requirement
  - Low resistance “ohmic” contacts
  - Low sheet resistance
  - Reliable interconnections

# Metallization Process

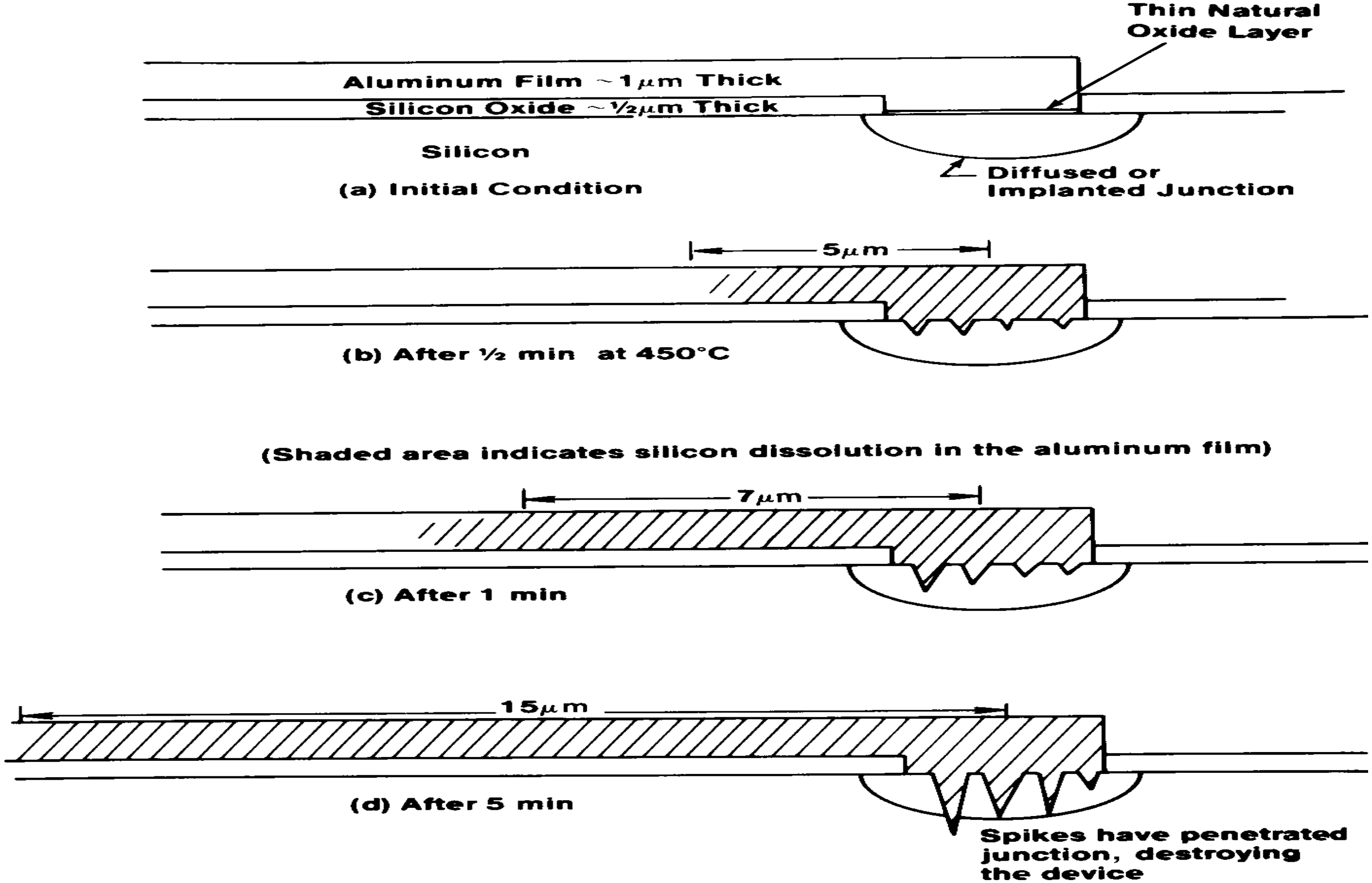
## Choice of Metal

- Advantages of Al
  - Inexpensive
  - Ease of forming contacts
  - Excellent adherence to Si and $SiO_2$
  - Low bulk resistivity (2.7 $\mu\Omega$-cm)
  - Excellent bondability
  - Easy to process

- Disadvantages
  - Spiking
  - Not sustain higher temperature over 450 °C

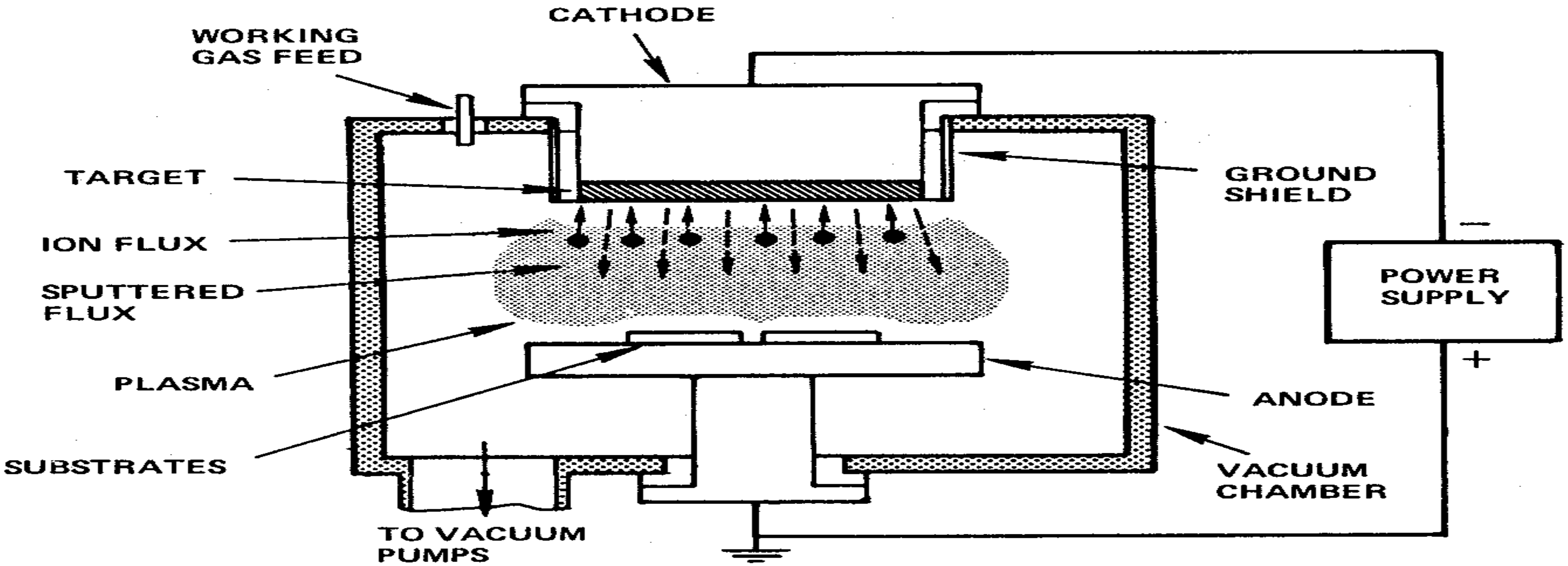
# Metalization Process

## Spiking



# Metalization Process

## Sputtering

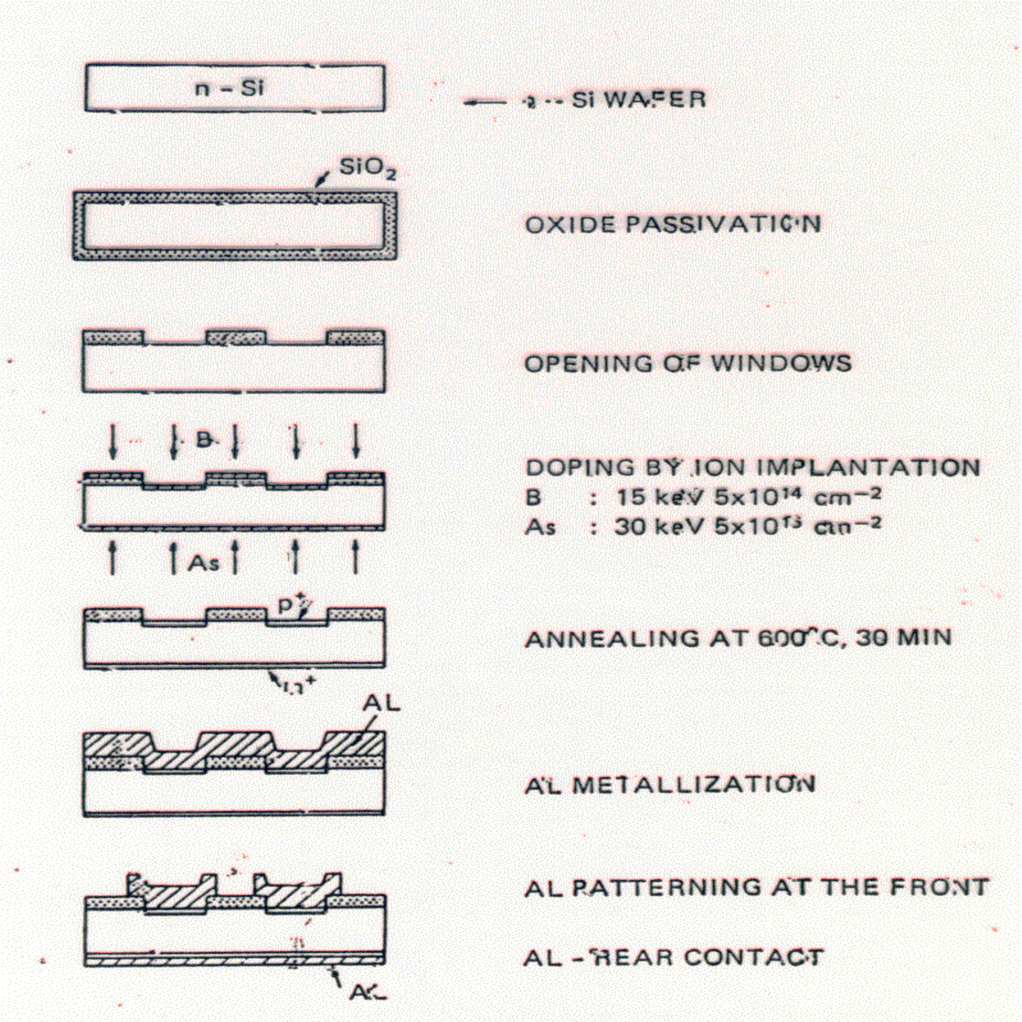


# Metalization Process

## Sintering

- To ensure good contact formation, Al is normally sintered at 450°C following deposition and patterning
- Si diffuses into the Al during sintering. The diffusion may cause spiking
- To prevent spiking
  - use Al-Si alloy (~1% Si)

# Flowchart of The Detector Process

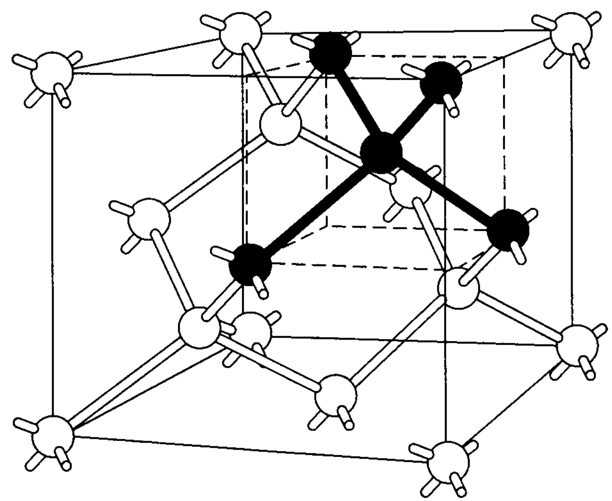


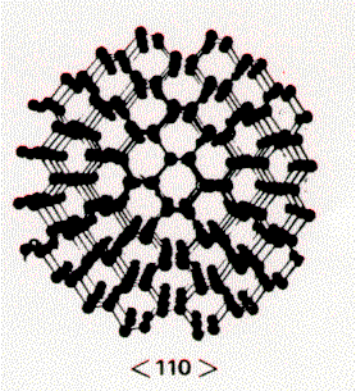
# Our Facility and Products

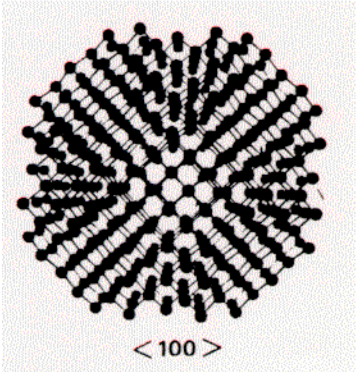
- Class 100 cleanroom, equipments, simulation tools,  mask design tools and testing equipments.
- Strip, Pad, Drift chamber, Pixel and Active matrix detector
- We are the only one in this business

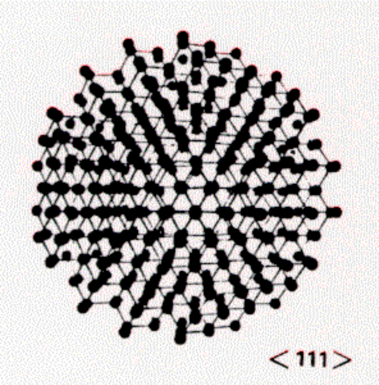
# Basic Silicon Properties

## Silicon Structure



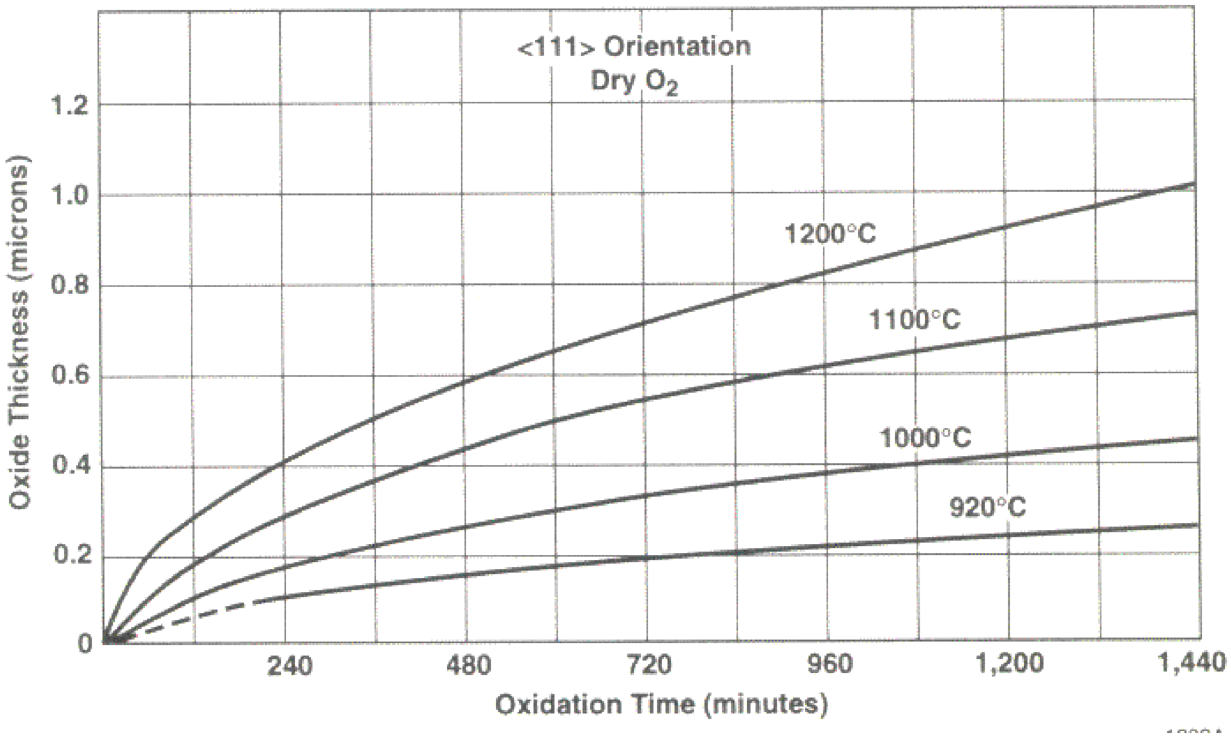


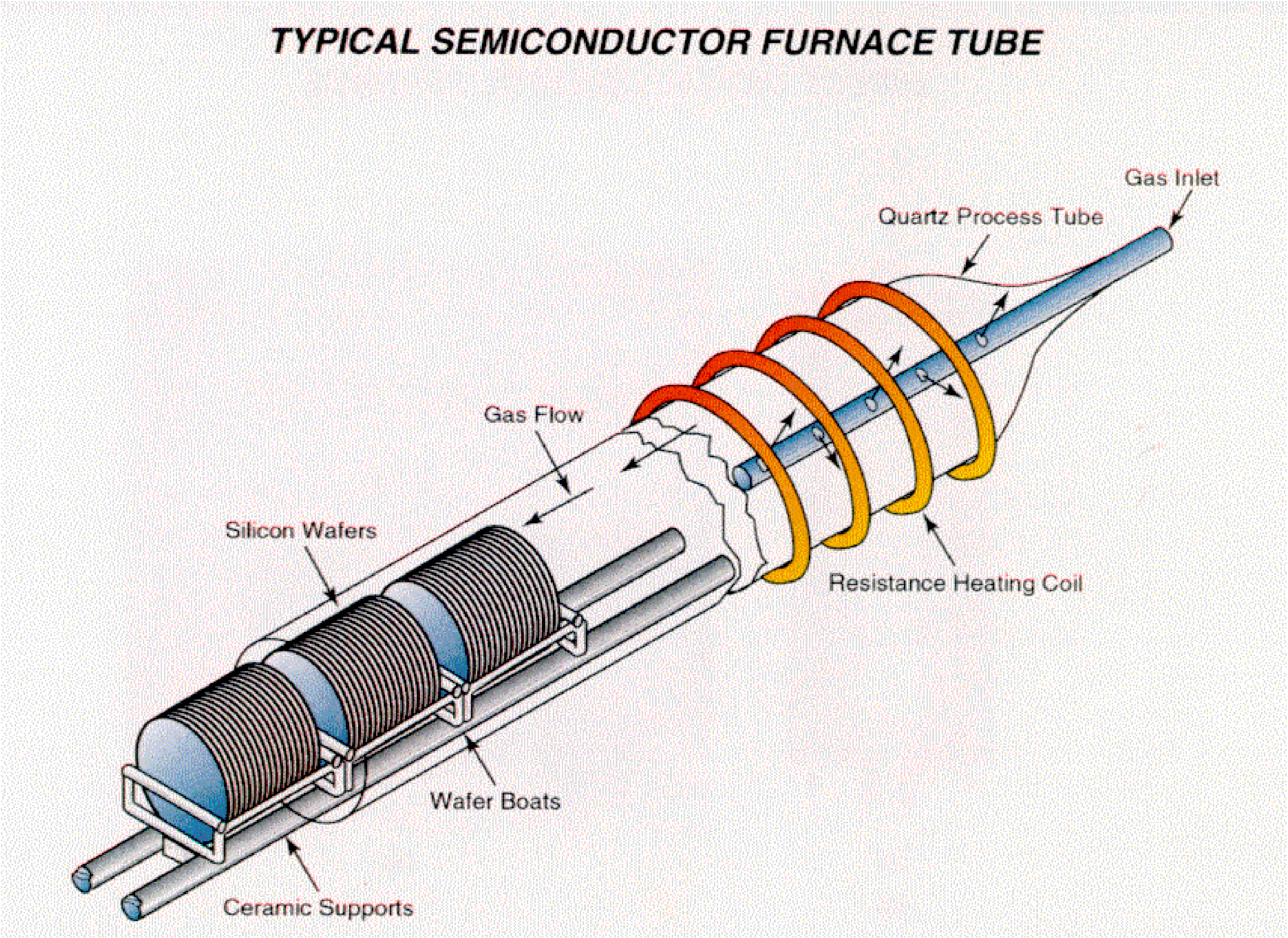



# Oxidation Process

## Temperature influence

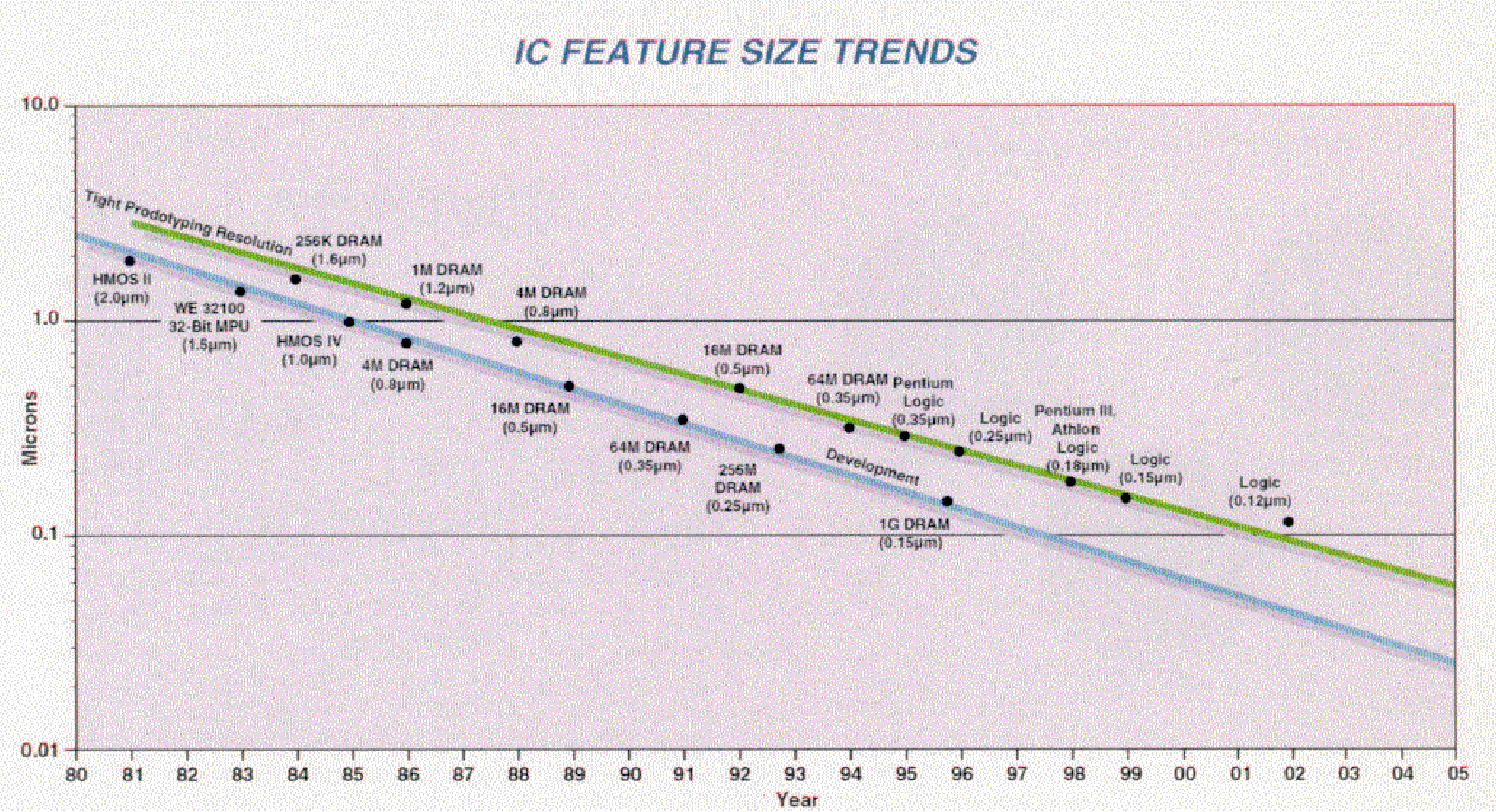


# Oxidation Process

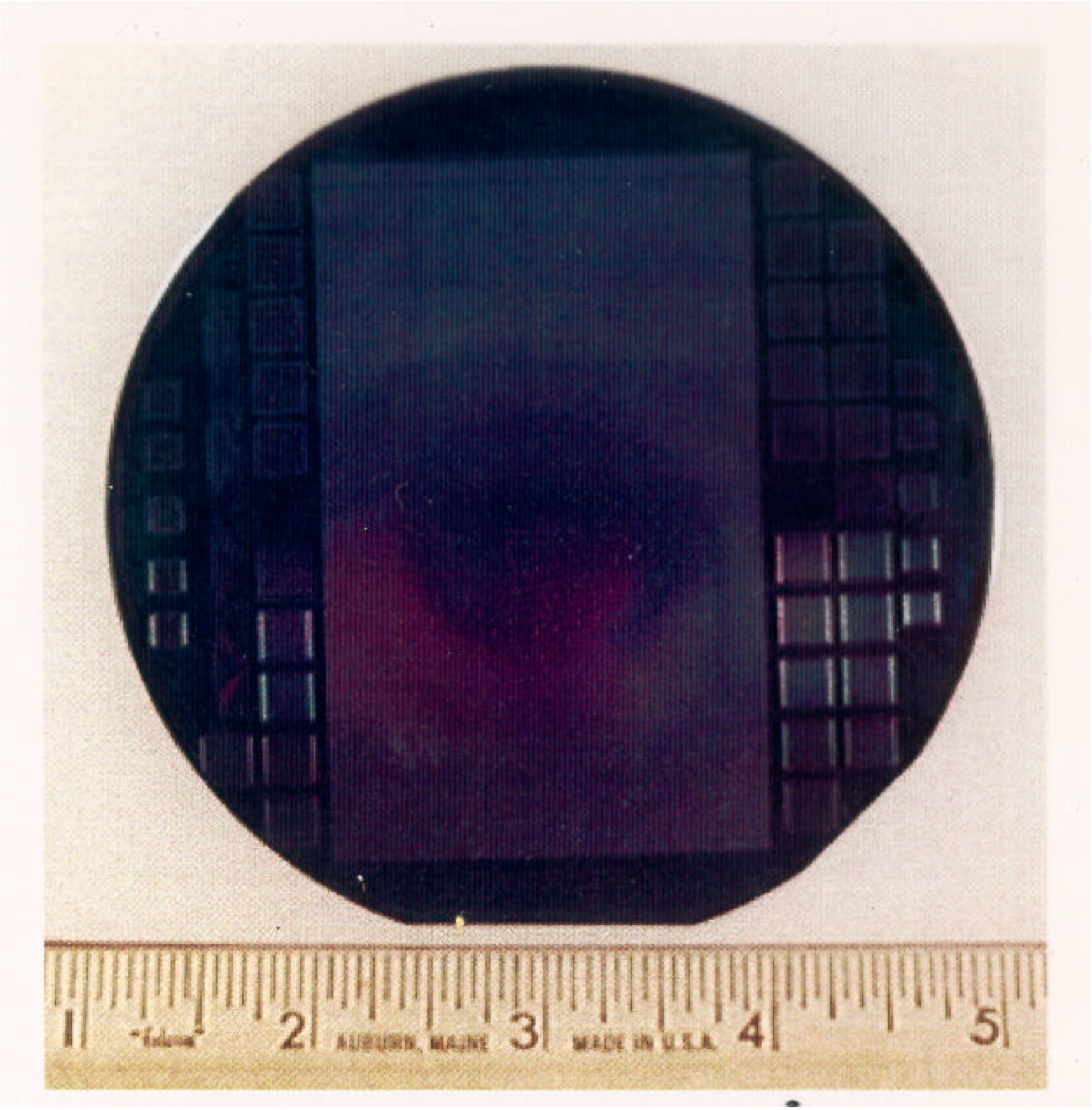


# Photolithography Process

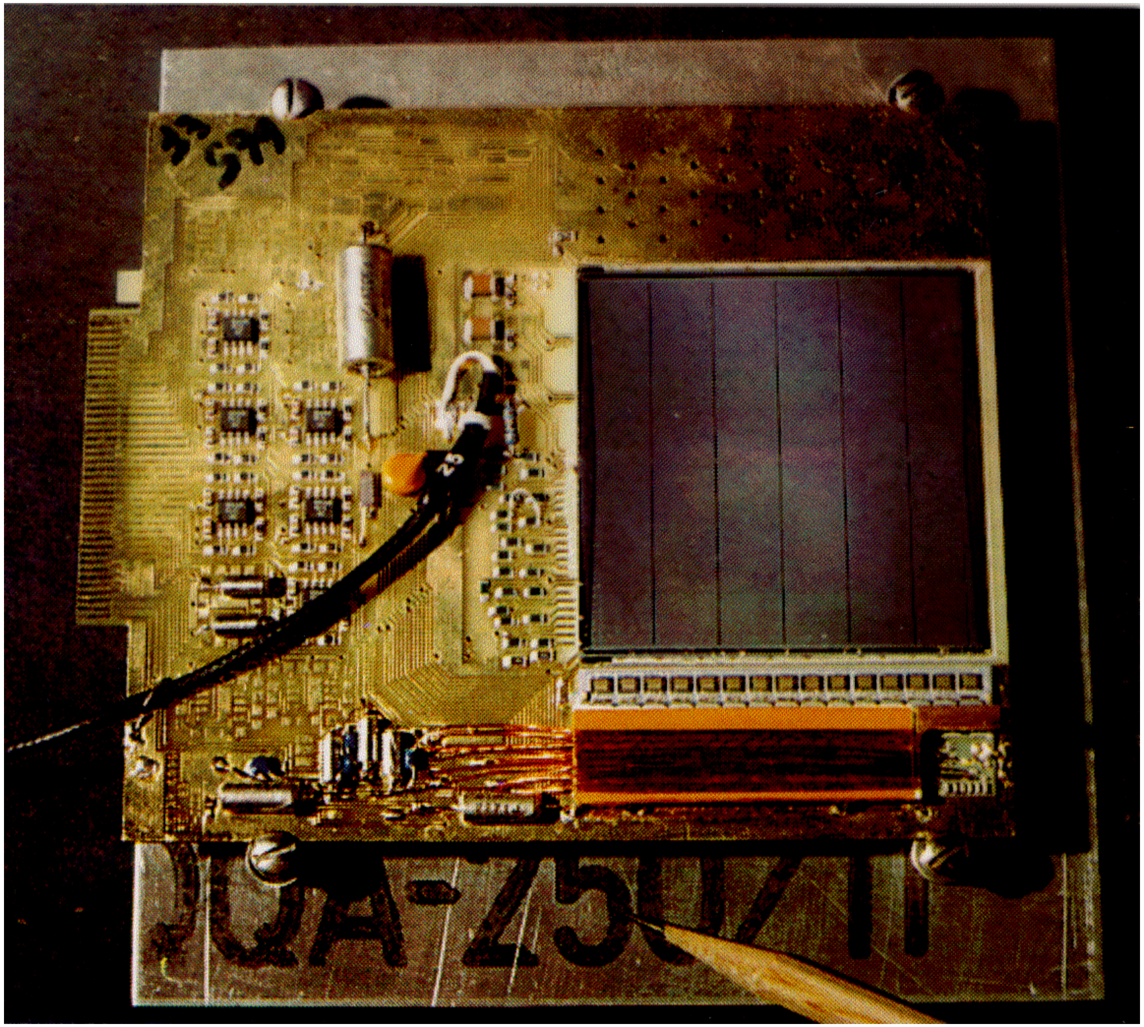
## Industry Trend



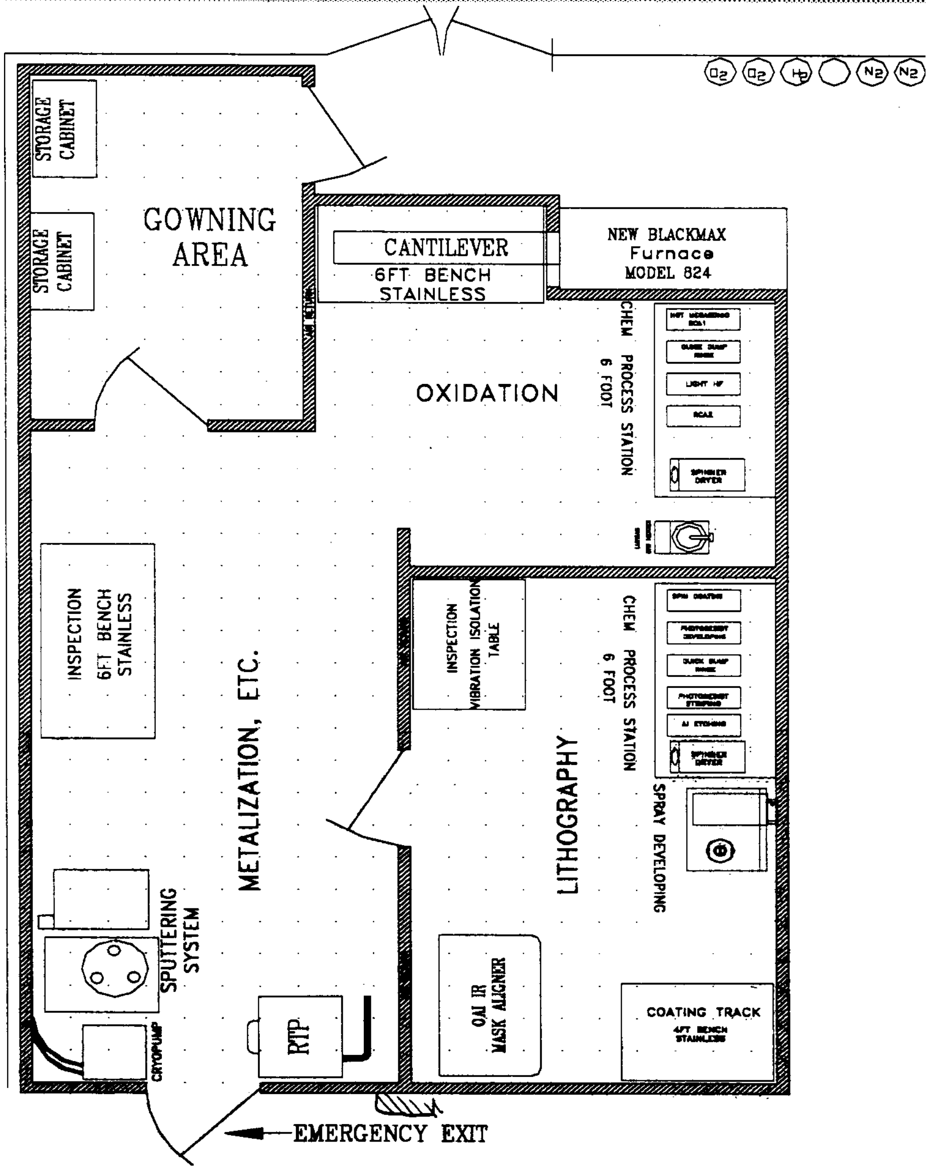
# Strip Detector



# Drift Chamber Detector



# CLASS-100 CLEANROOM



# Sputter